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SIFCON WITH SAND

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This report documents the development of preliminary material properties for slurry infiltrated fiber concrete (SIFCON) using fine-grained sands. Included in the report are the test procedures, test results, SIFCON material costs and conclusions.

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METRIC CONVERSION TABLE

To convert from	To	Multiply by
Fahrenheit (°F)	Celsius (°C)	5/8 (F - 32)
inch (in)	millimeter (mm)	25.4
foot (ft)	meter (m)	0.3048
pound/square inch (lb/in^2, psi)	kilopascal (kPa)	6.895
kips/square inch (k/in^2, ksi)	megapascal (MPa)	6.895
ounce (oz)	kilogram (kg)	0.02835
pound (lb)	kilogram (kg)	0.45
ounce (oz)	cubic centimeters (cm^3)	29.57
gallon (gal)	cubic meters (m^3)	0.00379

1.0 INTRODUCTION

1.1 OBJECTIVE

This report documents a material properties development program involving slurry infiltrated fiber concrete (SIFCON). This program investigated the use of sand in SIFCON slurries and was a part of a larger research project concerning the use of SIFCON in large-scale construction. The results of the larger project are documented in a separate report (Ref. 1). Both programs and both reports were performed by the New Mexico Engineering Research Institute (NMERI) for the Air Force Weapons Laboratory (AFWL) under Subtask 2.15.

1.2 BACKGROUND

NMERI has been using SIFCON in various applications since 1983. In 1985 a SIFCON material properties development program was begun. The initial program studied some SIFCON material properties in compression and a report documenting the results was produced (Ref. 2). In 1987 a second program was completed documenting SIFCON material properties in flexure (Ref. 3).

In the SIFCON flexure program, preliminary studies were performed using sand in SIFCON slurries. Although the study was preliminary, the use of sand in SIFCON was found to be advantageous. The program also identified some problems and limitations in using sand. The potential advantages warranted further study to attempt to find solutions and to define the limitations of some of the problems. This report summarizes further preliminary work in these areas.

1.3 NEED

The advantages of using sand in SIFCON slurries are at least twofold. First, the use of sand lowers the cost of a very expensive slurry. The use of sand adds mass to the slurry matrix: therefore, it replaces other more expensive ingredients such as cement. Second, the sand enhances the SIFCON material properties. The sand in the slurry produces a denser matrix, increases durability, reduces cracking from shrinkage, and does not significantly lower SIFCON strength properties.

The major problem encountered in the use of sand in SIFCON concerns the ability of the slurry to infiltrate the dense bed of steel fibers used in SIFCON manufacture. Only slurries with relatively

low viscosities are useful in the manufacture of most SIFCON. The addition of sand in slurries introduces at least three major problems to infiltration.

The first problem concerns slurry viscosity. The more sand that is added to a given slurry mix, the more viscous the slurry becomes. The more viscous a slurry becomes, its ability to infiltrate a given fiber bed decreases. Therefore, for a given mix with a given water/cement plus fly ash ratio (W/C+FA), there is a limit to the proportion of sand that can be added and still ensure proper fiber infiltration. Another factor affecting viscosity is sand gradation. For a given quantity of sand and a given slurry, the addition of different gradations of sands will result in different slurry viscosities.

The second problem concerns a filtering effect of the fibers. The fibers tend to filter out sand grains at the surface of the fiber bed. When enough sand grains are filtered out at the surface, the rest of the bed is sealed off from proper infiltration. This often results in voids in the SIFCON. Consequently, the greater viscosity of the slurry, larger sand grain size, and the density of the fiber bed can all contribute to difficulty of slurry infiltration.

A third problem involves the settlement of sand. In fluid mixes, the sand grains tend to settle to the bottom of the slurry. The larger the grain size and the higher the fluidity of the slurry, the greater is the tendency of settlement.

These problems in the use of sand in SIFCON slurries made the research of this program necessary.

1.4 SCOPE

The scope of this program was threefold. The main purpose was to identify and solve as many of the problems associated with fiber infiltration of SIFCON slurries containing fine-grained sands as practical. Secondly, the program attempted to develop a few high-strength SIFCON mixes containing sand that would be useful in large-scale SIFCON applications. Third, the program developed material costs for SIFCON mixes containing sand and mixes without sand. From this data the cost savings introduced with the use of sand can be seen.

2.0 TEST PROCEDURES

2.1 INTRODUCTION

This preliminary program was performed in two phases. The first phase primarily focused on defining the factors that affect infiltration of sand slurry into SIFCON steel fibers. This phase is identified as the infiltration study. To accomplish this, several tests were performed. These tests are described below. The purpose of the second phase, designated as the selected SIFCON study, was to observe the effects on compressive strength when using sand in selected SIFCON mixes. To accomplish this, five different mixes were prepared and SIFCON slabs were molded. From these slabs cored test specimens were removed and tested after 30 days for uniaxial unconfined compressive strength.

2.1.1 Mix Parameters

Since there were two phases of this program there were two groups of mixes. The first phase, relating to infiltration, contained four sets of mixes--each concerned with a different sand type. Table 1 presents all the parameters and tests studied with these four sand types. In general, fluid and moderately viscous mixes were made using each sand type. The fluid mixes contained a water/cement plus fly ash (W/C+FA) ratio of 0.40 while the moderately viscous mixes contained a ratio of 0.35. One mix using the finest grain size sand was made with a ratio of 0.30. This mix was found to be very viscous even with low sand percentages. Within each major mix, all slurry ingredients were held constant except the sand percentage. The various tests and observations noted in Table 1 were then performed on these slurries having different sand percentages.

Three tests were performed and observations made on the slurry mixes of the first phase. The tests included ASTM C-939 flow tests, cube strength tests and a specially devised test designated as the penetration test. The flow test was used to measure the relative fluidity of the slurries. The cube strength test was used to measure the uniaxial compressive strength of the slurries. The penetration test was an attempt to measure the relative ability of sand slurries to penetrate various fiber types. Observations were also made on saw cut specimens of SIFCON containing all the slurries produced in this phase.

The second phase of the study attempted to develop various high-strength SIFCON mixes containing fairly high percentages of fine-grained sands. These mixes contained either 50, 100, or 150 percent sand with respect to the cement. Besides the typical SIFCON ingredients some of the

Table 1. Slurry infiltration study test parameters.

Sand type	W/C+FA ratio and identification	Sand/cement, %	Cube and flow tests	Penetration tests	Photographs of cylinders
50 mesh sand	0.40 (S-5Mx-40-30)	0	C & F		
		50	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		100	C & F	P	ZL 30-50, ZL 50-50, ZL 60-80
		150	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		200	C & F		ZL 30-50, ZL 50-50, ZL 60-80
	0.40 (S-5M100-40-30 B)	100	F	P	
	0.30 (S-5Mx-30-30)	0	C & F		
		50	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		100	C & F	P	ZL 30-50, ZL 50-50, ZL 60-80
		150	C & F		ZL 30-50, ZL 50-50, ZL 60-80
	0.35 (S-5M100-35-30 B)	100	F	P	
30 mesh sand	0.40 (S-3Mx-40-30)	0	C & F		
		50	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		100	C & F	P	ZL 30-50, ZL 50-50, ZL 60-80
		150	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		200	C & F		ZL 30-50, ZL 50-50, ZL 60-80
	0.40 (S-3M100-40-30 B)	100	F	P	
	0.40 (SG-3Mx-40-30)	0	C & F		
		50	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		100	C & F	P	ZL 30-50, ZL 50-50, ZL 60-80
		150	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		200	C & F		ZL 30-50, ZL 50-50, ZL 60-80
	0.35 (S-3Mx-35-30)	0	C & F		
		50	C & F		ZL 30/50, ZL 50-50, ZL 60/80
		100	C & F	P	ZL 30-50, ZL 50-50, ZL 60-80
		150	C & F		ZL 30-50, ZL 50-50, ZL 60-80
	0.35 (S-3M100-35-30 B)	100	F	P	
Fine blasting sand	0.40 (S-FBSx-40-30)	0	C & F		
		50	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		100	C & F	P	ZL 30/50, ZL 50-50, ZL 60-80
		150	C & F		ZL 30-50, ZL 50-50, ZL 60/80
		200	C & F		ZL 30-50, ZL 50/50, ZL 60/80
	0.40 (S-FBS100-40-30 B)	100	F	P	
	0.35 (S-FBSx-35-30)	0	C & F		
		50	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		100	C & F	P	ZL 30-50, ZL 50-50, ZL 60-80
		150	C & F		ZL 30-50, ZL 50-50, ZL 60-80
Washed plaster sand	0.40 (S-SPx-40-30)	0	C & F		
		50	C & F		ZL 30-50, ZL 50-50, ZL 60-80
		100	C & F	P	ZL 30-50, ZL 50-50, ZL 60-80
		150	C & F		ZL 30-50, ZL 50-50, ZL 60-80
	0.40 (S-SP100-40-30 B)	100	F	P	

slurries also contained microsilica. Three different fiber types were infiltrated into each of the slurries to produce the SIFCON. Emphasis was placed on finding mixes that would result in good infiltration. Much of the information obtained in the first phase was used to design these mixes.

2.1.2 Mix Ingredients and Proportions

The mix ingredients used in this study are listed in Table 2. The ingredients that were used in every mix included cement (in bagged form), water, and superplasticizer. Fly ash (in bagged form) was used in all slurry infiltration study mixes and only two selected SIFCON study mixes. One of four different types of sand, designated by the suppliers as 50 mesh (bulk), 30 mesh (bulk), washed plaster (bulk) or fine blasting sand (bagged), were used in all mixes. All sands used were commercially available and obtained from local suppliers. Table 3 presents the properties of the four sand types. Most of the property information was obtained from the suppliers. NMERI checked the sieve analysis as shown in the table. A clean, coarse concrete aggregate from a NMERI stockpile of unknown source was also used in a few tests in the selected SIFCON study mixes only. One of three types of steel fibers (uncollated), designated as ZL 30/50, ZL 50/50, or ZL 60/80, were used in the selected SIFCON study mixes only. One of two types of microsilica, designated as EMS 960 (bagged) or Force 10,000 (fluid), were used in four of the five selected SIFCON mixes only. Only one infiltration mix contained a small percentage of a bentonite viscosifier.

TABLE 2. Mix Ingredients.

Ingredients	Description	Supplier	Applicable mixes
Cement	ASTM C-150	Quickrete	All
Fly ash	Class C	Front Range Fly Ash	Infiltration tests and selected mixes
Water	Facility 26025 tap water	Kirtland A.F. Base well no. 2	All
Microsilica	EMS 960 (bagged) Force 10,000	Elkem Chemicals Inc. W. R. Grace & Co.	Selected mixes Selected mixes
Bentonite	Quik-Gel viscosifier	NL Baroid	Infiltration tests
Superplasticizer	400N	Master Builders, Inc.	All
Fiber	ZL 30/50, ZL 50/50, ZL60/80	Bekaert Steel Wire Corp.	Selected mixes Selected mixes
Sand	50 mesh, 30 mesh, washed plaster 50 mesh, 30 mesh Fine blasting	Springer Building Materials Albq. Gravel Products	Infiltration tests Selected mixes Infiltration tests
Aggregate	3/4" concrete aggregate	NMERI stockpile	Infiltration tests

TABLE 3. Sand properties.

Sand type	50 mesh sand		30 mesh sand		Fine blasting sand		Washed plaster sand		Aggregate
	NMERI	Supplier	NMERI	Supplier	NMERI	Supplier	NMERI	Supplier	NMERI

Sieve analysis

Sieve size, no.	Passing sieve, %								
1"									100.00
3/4"									97.74
1/2"									35.47
3/8"									2.80
4					100.00		99.76	100.00	0.08
8						100.00		99.00	
10					99.93		95.35		0.06
16						99.70		88.00	
20	100.00		100.00		99.73		76.63		
30				100.00		98.00		70.00	
35				90.00					
40	98.12	100.00	29.85	68.00	75.90	86.20	32.82		0.00
45		94.00		52.00					
50		73.00		27.00		58.50		28.00	
60	36.25	51.00	3.04	16.00	25.08		9.05		
70		3[illegible].00		10.00					
80		20.00		2.00		24.80			
100		9.00		1.00		17.70		5.00	
120		4.00							
140	3.07	2.00	0.10	0.00	1.57		0.58		
200	1.12		0.04		0.00	6.70	0.15	3.00	

Specific gravity

-	2.59	-	2.59	-	2.58 - 2.60	-	2.59	

Absorption, %

-	1.2	-	1.2	-	0.8	-	1.2	

Suppliers

Springer Building Materials	Albuquerque Gravel Products	Springer Building Materials	Unknown

Tables A1 and B1 in Appendixes A and B present all the specific mix proportions for the two phases of this program respectively. The major variables of the slurry infiltration study mixes (Table A1) were the sand type and the percentage of sand with respect to the cement. These mixes are grouped according to the water/cement plus fly ash (W/C + FA) ratio. The two major groups included fluid and moderately viscous mixes at 0.40 and 0.35 W/C + FA ratios respectively. One major mix contained a W/C + FA ratio of 0.30. It turned out to be very viscous.

The selected SIFCON study mixes (Table B1) were trial batches used to verify and expand the findings of the slurry infiltration study mixes. This slurry was then used to mold SIFCON sample slabs by infiltrating three different fiber types and one containing a combination of fiber and a concrete aggregate. Core specimens were removed from these slabs and tested for compressive strength.

Every mix in this study had a unique identification code. The code had a relationship to the major mix proportions. Figure 1 interprets the meaning of each identification code in the slurry infiltration study. The mixes with the "x" in the place of the sand percentage indicates that a slurry was initially made omitting the sand and then smaller portions of that same slurry were mixed with the different sand percentages. These mixes are always followed in Table A1 with the final slurry mixes containing the varying sand percentages. This procedure was followed to ensure that the slurry without the sand was identical for each individual sand percent.

The identification codes for the selected SIFCON mixes (Table B1) are similar to those of the infiltration study mixes. Figure 2 interprets the meaning of each of these identification codes. The only difference is that some mixes have three sets of numbers at the end instead of the two. When there are the three sets of numbers, the first set indicates the percent of microsilica with respect to the cement in the mix. The last two numbers represent the same proportions as the slurry infiltration study mixes.

2.2 SLURRY INFILTRATION STUDY TEST PROCEDURES

2.2.1 Slurry Mixing

The following procedures were used on the major slurry infiltration study mixes where the sand percentages were varied. A copy of the specific procedures checklist used by the laboratory technicians is contained in Appendix C. First, a relatively large batch of the slurry ingredients without sand was mixed. Experience has shown that the best order of ingredient mixing is to

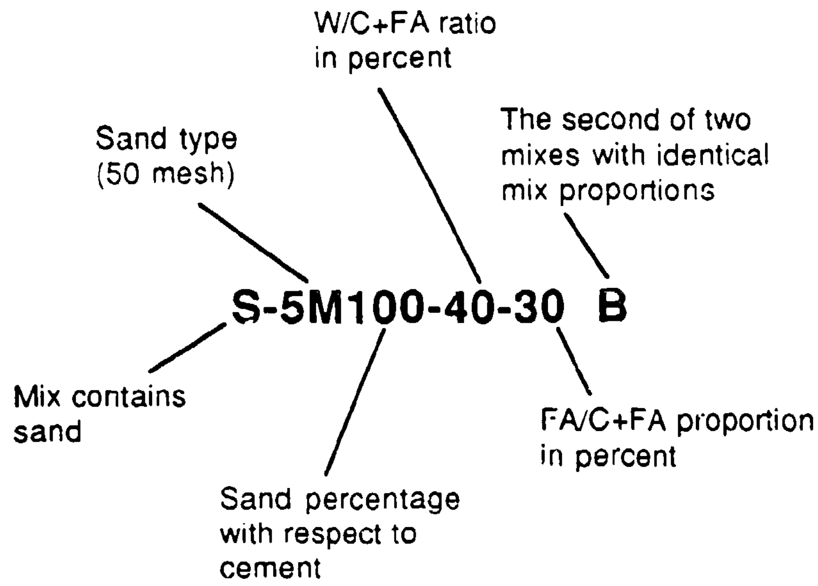


Figure 1. Mix identification codes for infiltration study mixes.

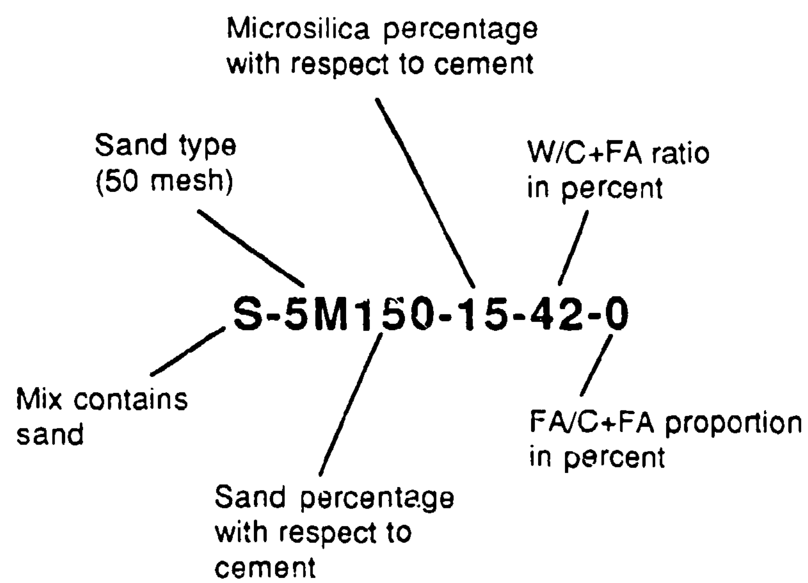


Figure 2. Mix identification codes for selected SIFCON study mixes.

first, mix the water with the superplasticizer; next, add the fly ash; and finally, add the cement and any other additives. After thorough mixing, proportional predetermined smaller batches of this slurry were weighed out to correspond to the preweighed sand percent (refer to the second page of the technician's procedure checklist sheets in Appendix C). All sands were dried out before preweighing so that the appropriate absorption water could be added. After the sand was added the smaller mixes were thoroughly mixed. The percent of sand ranged from 0-200 with 50-percent increments (Table 1). Some mixes, however, were too viscous to allow the 200-percent sand to be used; for these mixes only 150-percent sand was added. From these smaller mixes several tests were performed and observations made.

2.2.2 Fluidity Tests

A major factor affecting infiltration of slurry into steel fibers is the fluidity of the slurry. Therefore, fluidity measurements were taken using the ASTM C-939 flow test. The test simply involves measuring the amount of time required for a given volume of slurry to pass through a standard flow cone. A flow measurement was taken at approximately 6 to 7 min after initial mixing of the slurry. Since slurries lose fluidity with time, flow measurements were also taken at increments of time up to approximately 4 h after initial mixing. The slurry was premixed briefly before each flow test. All flow measurements are presented in Table A2. From these data it can be determined relatively how well a given slurry will infiltrate the fibers, and how long the slurry can be kept on hand before it becomes too viscous to infiltrate the fibers safely. The time from initial mixing to when infiltration may be questionable is designated as mix open time.

2.2.3 Penetration Tests

A major obstacle to infiltration of slurry containing sands into steel fibers is the filtering effects of the fibers. Different fibers retain more sand particles within the fiber bed while others more readily permit the particles to penetrate. A test was devised to measure the relative ability of sand slurries to penetrate fibers (penetration test).

Since there are no known comparable tests, some procedures may seem arbitrary. These were adapted for consistency and practicality. The test consisted of passing a known volume of slurry through a constant-volume fiber bed and then determining the percentage of slurry passing through the fibers. The constants included the same slurry ingredients and proportions, the same procedures, and the same volume of slurry and fibers. The variables included four different sand types

and three different fiber types. In general, two different slurry fluidity levels were also used. These consisted of a fluid and a moderately viscous mix.

The following procedures were used in performing the penetration test. Standard aggregate sieves were used in this test. Steel fibers were first randomly rained into a 2-in depth in a No. 20 sieve. The sieve was placed on a pan. The fiber bed was then vibrated for 30 s, and more fibers were added to compensate for any settlement during vibration. Next, a well-mixed constant volume of slurry was slowly passed through the fiber bed and caught by the pan. Care was taken to prevent any slurry from overflowing the sieve. The sieve and pan were then allowed to set for 20 min to allow the slurry to penetrate the fiber bed. The percentage of the slurry penetrating the fiber bed was determined by dividing the weight of the slurry passing the fiber bed by the weight of the total slurry poured over the fiber bed.

2.2.4 Settlement Observations

It has also been observed that there is a tendency of sand particles within sand slurries to settle to the bottom of the slurry. The tendency for settlement appears to vary with fluidity and particle size. SIFCON specimens were prepared for purposes of visual observation of this settlement.

The following procedures were used in preparing the specimens. A conventional cylinder mold was filled with one of the fiber types. The fiber was randomly rained in and then vibrated for 2 min. After the specific slurry was adequately mixed, it was poured through the fiber bed in the cylinder mold. An attempt was made to keep the slurry from flowing down the sides of the cylinder between the fiber and the mold wall. This is an area of lower fiber density that allows slurry to flow to the bottom at a nonrepresentative rate. With some slurries and some fiber types this could not be prevented. If a slurry was too viscous to pass through the particular fiber type, varying amounts of vibration were applied in an attempt to get infiltration. After the cylinder was filled with slurry, the specimen was set inside the temperature control room for curing. After several days these cylinders were then saw cut vertically, exposing a cross section of the SIFCON. Photographs of these sections were taken and observations of the infiltration and sand distribution were made.

2.2.5 Slurry Compression Tests

Slurry cubes were also molded for most of the mixes of this phase. After thoroughly mixing each slurry batch, a set of cubes was molded. It was observed that the sand in the slurry of many of

these cubes tended to settle to the bottom of the mold. The depth of this settlement was recorded. After 30 days of wet curing, the cubes were tested for uniaxial compression. In testing, the cubes were aligned on their sides with respect to their molded position, since these would be the smoothest and most parallel faces.

2.3 SELECTED SIFCON STUDY TEST PROCEDURES

2.3.1 Slurry Mixes

The purpose of the mixes in this phase was to develop workable high-strength SIFCON mixes using sand. The information that was gained in the first phase was used to design these mixes. An attempt was made to design slurries that were not only high strength but also had good infiltration qualities. Slurries were proportioned so that a 6-in-deep slab could be molded with minimal or no vibration. These slurries in general contained relatively large percentages of sand as well as other ingredients such as microsilica. In some samples an attempt was also made to introduce a preplaced concrete aggregate within the preplaced fiber bed.

The initial proportioning was based on estimates from other high-strength mixes not containing sand, plus the information gained from the first phase of this program. The initial water proportion was set so that a viscous mix would result. After a slurry batch was made using these initial proportions, the consistency, fluidity and tendency of sand settling was observed. Since these mixes were intentionally viscous, additional superplasticizer and/or water was added after initial mixing. An attempt was made to obtain a slurry with as low a W/C+FA ratio as practical, but at the same time viscous enough to keep the sand from settling, and yet fluid enough to properly infiltrate the fibers with minimal vibration. Such mixes would be practical only in large-scale SIFCON construction.

2.3.2 Slab Infiltration Observations

For each slurry mix, four SIFCON slabs were molded. Three of these contained the three different fiber types (ZL 30/50, ZL 50/50, ZL 60/80) while the fourth contained a mixture of the ZL 60/80 fiber type with a concrete aggregate evenly interspersed. The aggregate and fiber were placed simultaneously by sprinkling in proportionate amounts until the mold was filled. Each fiber bed was vibrated for 2 min. The aggregate percentage was measured by weighing a sufficient quantity of aggregate, then subtracting the quantity remaining after filling the mold. This weight was then compared to the proportional weight of the cement in the slurry. These four different slabs allowed

a comparison of not only SIFCON strength for the fiber types but also the relative ability of these fiber types to permit infiltration with the same slurry.

After the slurry was first produced, a flow measurement was taken. The flow measurement was used as the basis for the addition of more superplasticizer and/or water. Once the desired slurry fluidity was obtained, the slurry was poured through each of the four fiber beds. Vibration was applied only when the slurry was not infiltrating any one specific fiber bed properly. Observations were made on this infiltration procedure that would be helpful in modifying field-produced slurries.

2.3.3 SIFCON Compression Tests

After the four slabs were molded, they were water cured in a temperature controlled room. After several days, cored specimens were removed from these slabs. These specimens were prepared for uniaxial unconfined compression tests after 30 days of curing. The testing of the specimens included the plotting of complete stress versus strain curves.

Observations were also made on the cored specimens before testing. The quality of infiltration and the sand distribution within the specimens were observed.

3.0 TEST RESULTS

3.1 SLURRY INFILTRATION STUDY RESULTS

3.1.1 Fluidity Measurements

The results of all flow tests for this phase of study are presented in Table A2. The table is divided into three groups. The three groups include fluid, moderately viscous, and viscous mixes with W/C+FA ratios of 0.40, 0.35, and 0.30, respectively. Within each of these three groups, individual tables for each major mix are presented with that mix identification appearing at the top of the individual table. In the left-hand column of each individual table for each major mix are the specific times with respect to the initial mix start time (T=0) that the individual flow tests were performed. At the top of the individual tables are the different sand percentages represented within the major mix. Within the table itself are the actual flow measurements in seconds.

The most obvious overall result is that a decrease in the W/C+FA ratio results in slurries of greater viscosity. Equally obvious is that, for a given slurry, an increase in sand percentage results in an increase in the viscosity of the sand and slurry combination. The slurries also tend to become more viscous with increased time with respect to the initial mix time. Comparing the different sand types does not reveal any drastic differences in fluidity. The three fine grained sands--50 mesh, 30 mesh, and fine blasting sand--show similar flow measurements, especially at the lower sand percentages. The washed plaster sand appears to result in a slightly more viscous sand slurry combination. The addition of the bentonite viscosifier tended to increase viscosity. The purpose in using this viscosifier was to see if it would control sand settlement. This will be discussed later in this report.

Open time for the mixes varied considerably. In this report, open time is defined as the length of time from initial mixing of the slurry ingredients (T = 0) to the time when the flow measurement reaches or exceeds 50 s. Practical experience has shown that a slurry without sand with a flow measurement of less than 50 s will infiltrate most fibers without any vibration of the fiber bed during infiltration. For mixes that were initially fluid, the open time exceeded 4 h, except for those slurries containing 200-percent sand and the slurry with the viscosifier plus 150-percent sand. In the tables, the open time is delineated by the lines within the flow measurement portion of the individual tables. For the moderately viscous and viscous mixes, 150 percent was the maximum practical quantity of sand used. The open time for the moderately viscous mixes also was fairly long but shorter than for the fluid mixes. The one viscous mix was too viscous even at

initial mixing to ensure proper infiltration without any vibration; therefore, the open time would be less than 8 min for all those sand percentages.

3.1.2 Penetration Tests

The penetration test was intended to give a relative measure of the ability of sand slurries to penetrate different fibers at different levels of fluidity. Table 4 presents the results of the tests. The test was performed for those mixes presented in the table and using the three fiber types considered in this study. The mixes were proportioned such that three viscosity levels were obtained--fluid, moderately viscous, and viscous mixes with W/C+FA ratios of 0.40, 0.35 and 0.30, respectively. Also contained in the table is a fluidity measurement. The flow value at 30 min after initial mixing (T=0) gives another indicator of relative fluidity. Three other mixes are presented at the bottom of the table. The first of the three is that mix containing the viscosifier while the other two are mixes used in the selected SIFCON mixes phase of this study. These were tested simply for comparison purposes.

The results of these penetration tests represent the percentage of the sand slurry passing through a constant-depth fiber bed with respect to the total sand slurry poured on the surface. The results clearly indicate that the denser that fiber bed is, the lower is the percent penetration. This was expected. The ZL 30/50 fibers, being the densest at 9.4 percent by volume, had the lowest percent penetration in all except one mix (S-3M100-35-30 B). The ZL 60/80 fiber with the least dense fiber bed at 6.6 percent by volume had the highest percent throughout. There was little discernible difference between the different sand types. The reason for this may be one or all of three possibilities. First, there may not be any difference or only slight differences between the ability of these sands to penetrate the fibers. Second, the data may be too limited to establish any trends. Third, the tests were probably too imprecise to expose any differences. Whatever the reason, there clearly is a need to do much further study in this area.

3.1.3 Settlement Observations

In general, when sands were used in slurries, there was a tendency for the sand to settle out of the rest of the slurry. There also seemed to be a tendency for the fibers to filter sand out of the slurry at the surface of the fiber bed. Photographs were taken of cross-sectional cuts of SIFCON cylinders to observe these fiber infiltration problems. These photographs are presented in Appendix A (Figs. A1 through A84). The photos show the sand grain distribution inside a

TABLE 4. Penetration test results.

Mix identification code	Sand type	Fluidity: Flow at 30 min, s	Fiber type: ZL 30/50 9.4%	ZL 50/50 5.7%	ZL 60/80 6.6%
			Penetration, %		
Fluid mixes (W/C+FA = 0.40)					
S-5M100-40-30	50 mesh	16	12.6		
S-5M100-40-30 B		17	9.9	17.6	37.8
S-3M100-40-30	30 mesh	18	9.2		
S-3M100-40-30 B		17	6.4	9.4	14.9
S-FBS100-40-30	Fine blasting	15	10.5		
S-FBS100-40-30 B	sand	17	10.5	12.6	14.3
S-SP100-40-30	Washed	17	8.3		
S-SP100-40-30 B	plaster sand	15	8.2	25.2	28.1
Average		16.5	9.5	16.2	23.8
Moderately viscous mixes (W/C+FA = 0.35)					
S-5M100-35-30 B	50 mesh	37	5.1	5.3	10
S-3M100-35-30	30 mesh	17	11.3		
S-3M100-35-30 B		37	2.8	2.6	3
Average		30.3	6.4	4.0	6.5
Viscous mix (W/C+FA = 0.30)					
S-5M100-30-30	50 mesh	95	0		
er mixes					
SG-3M100-40-30	30 mesh	20	5.3		(Viscosifier used)
S-5M150-15-42-0	50 mesh	24	6.6		(Microsilica used)
S-5M100-10-37-0	50 mesh	40	0		(Microsilica used)

fiber bed. These photos are arranged in the order outlined in Table 1. The photos are grouped according to (a) sand type, (b) fluidity within the sand type, (c) the sand percentage within the major slurry mix, and (d) fiber type. In addition to showing the sand settlement and sand grain distribution within the fiber bed, the photos show other interesting infiltration characteristics such as the relative quantity of entrapped slurry air bubbles, voids, and the relative tendency for sand entrapment within the fiber bed.

It can be observed from the photos that in general nearly all mixes showed settlement of sand in most cylinders of the three fiber types throughout the full range of all sand percentages. Figure 3 is representative of this settlement. The only cylinders where no settlement was observed were in the cylinders of the one viscous mix. A few other cylinders with the ZL 30/50 fibers revealed little if any sand settlement. These tended to contain only 50-percent or 100-percent sand where it appeared that the fiber bed entrapped the sand that would otherwise have settled out. Figure 4 is representative of this tendency of sand entrapment instead of settlement. The other two fiber types entrapped very little sand.

The one viscous mix showed the best sand distribution throughout the fiber bed as shown in Figure 5. The mix appeared to be viscous enough to keep the sand particles suspended in the slurry. In order to achieve infiltration with this viscous mix, considerable vibration was applied to all except two of the cylinders.

The use of the bentonite viscosifier in a fluid mix did not seem to hold sand particles in suspension as hoped. It did, however, make the slurry a little more viscous than if it had been omitted. This increased viscosity seemed to account for the ability to hold particles in suspension in 5 of the 12 cylinders of this major mix. There was settlement of particles in all the other seven cylinders.

A few cylinders showed a failure of the slurry to infiltrate the fiber bed. This occurred when the sand percentage was 200, causing the slurry to become viscous. This failure occurred only in the slurries that were initially fluid before the addition of the sand. It did not occur in any of the moderately viscous or viscous mixes. In the moderately viscous and viscous mixes 200-percent sand was not even attempted. During the preparation of these cylinders, observations indicated they would not have successfully infiltrated with 200-percent sand. This indicates that about 200-percent sand is probably an upper limit for most SIFCON slurries. The cause of the failure to infiltrate was observed to be a tendency for the fiber bed to filter sand particles out of the rest of the slurry at the surface. This occurred when the sand percentage was high and the slurry too viscous

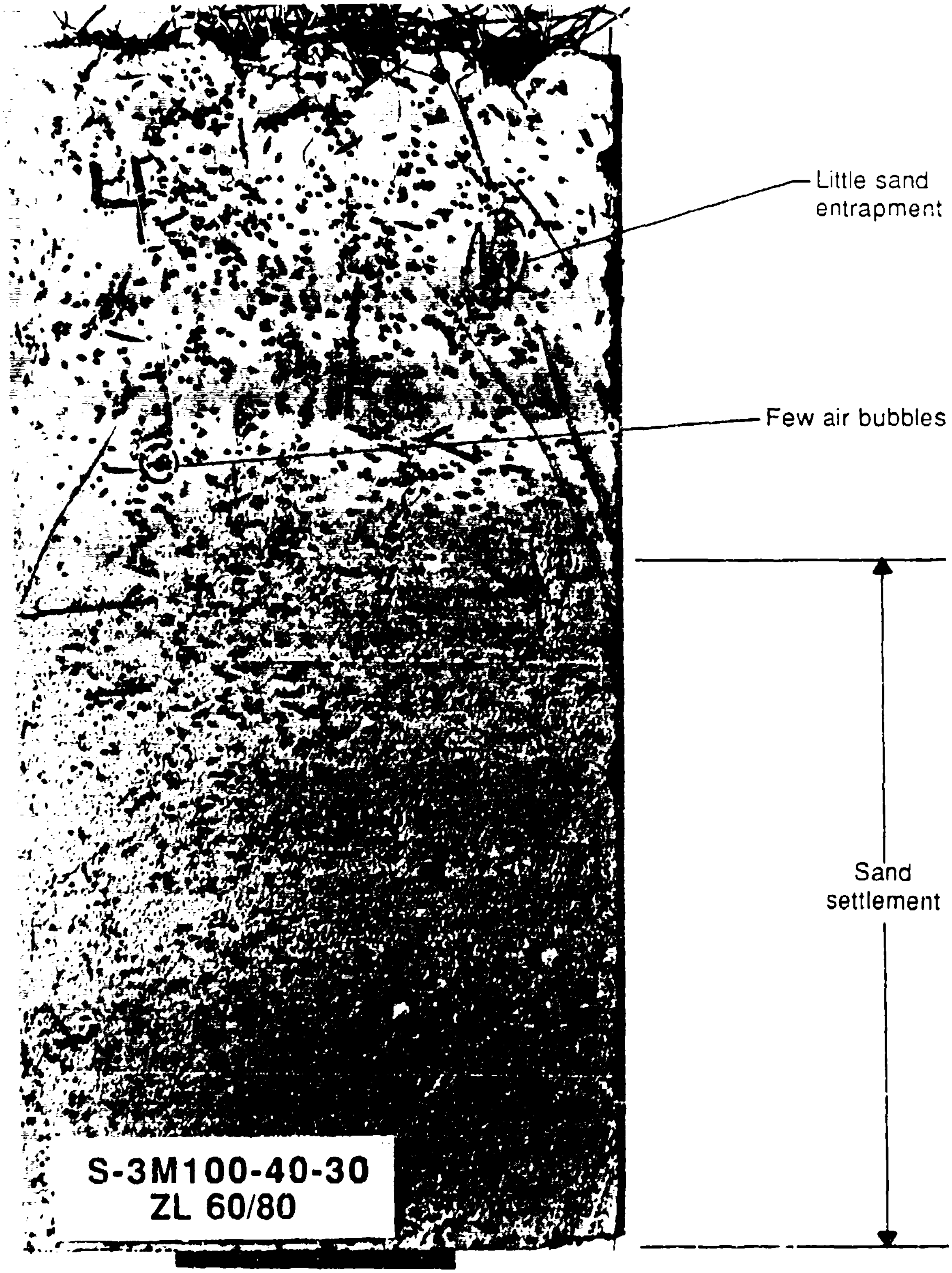


Figure 3. 30-mesh sand (100%) in fluid mix -- ZL 60/80 fibers.

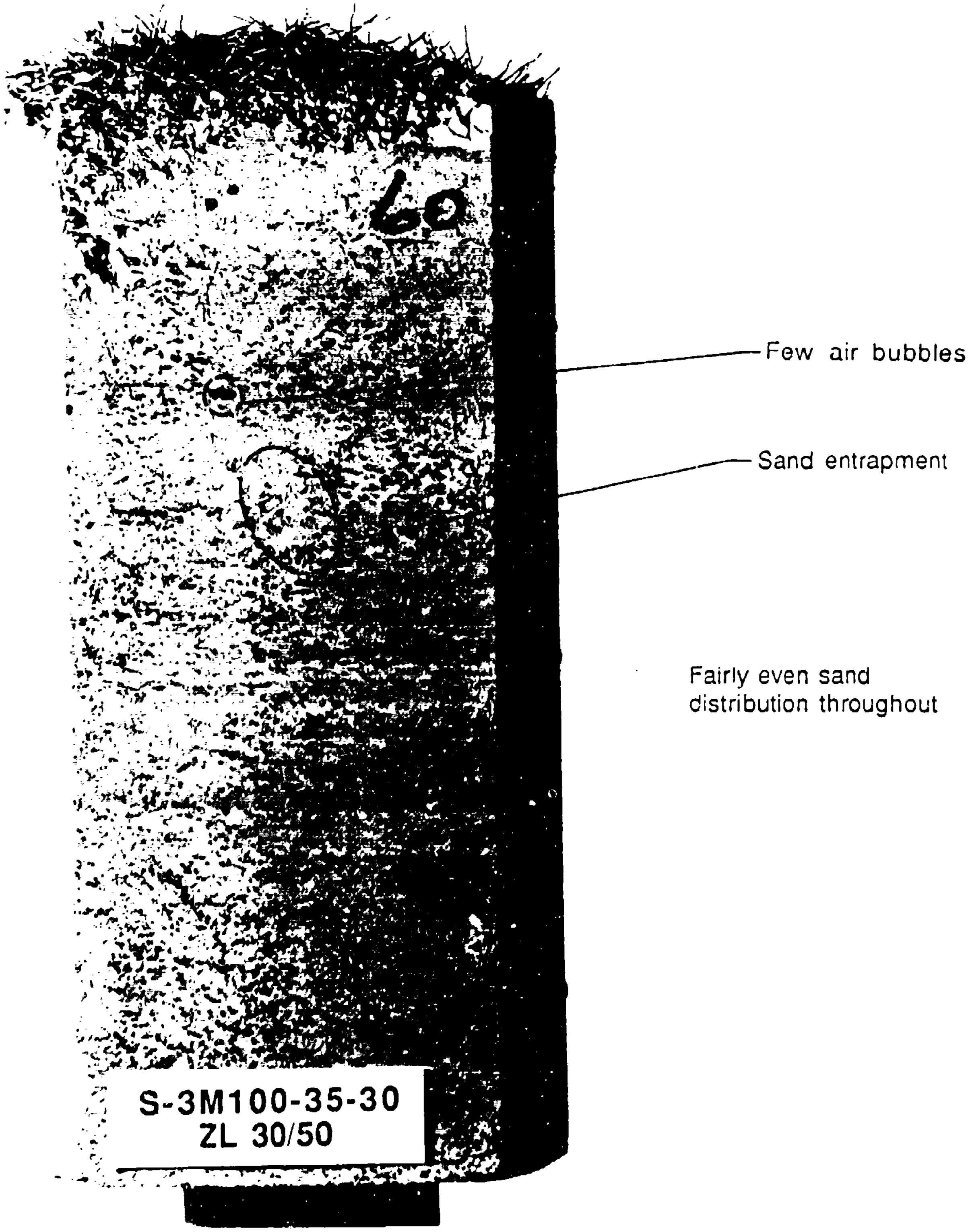


Figure 4. 30-mesh sand (100%) in moderately viscous mix -- ZL 30/50 fibers.

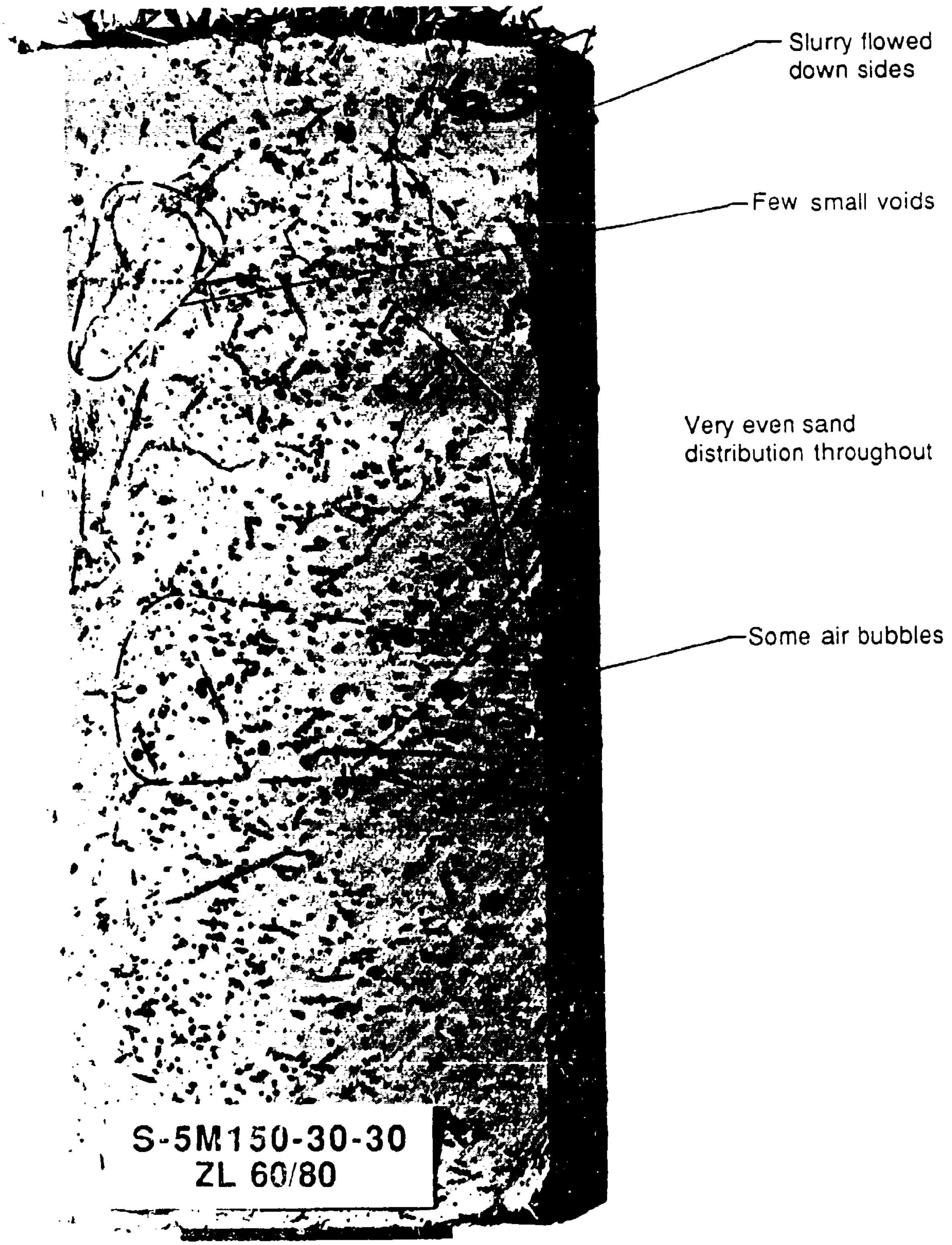


Figure 5. 50-mesh sand (150%) in viscous mix -- ZL 60/80 fibers, moderate vibration.

to "wash" the particles down into the fiber bed. After enough sand particles were filtered out, the fiber bed became so clogged that the bed became essentially sealed off, preventing further infiltration. Figures 6 and 7 illustrate the results of this fiber clogging. These figures also show that there are potentially different degrees of this effect. Figure 6 shows the use of the denser ZL 30/50 fiber after considerable vibration. Figure 7 represents the identical slurry but with ZL 50/50 fiber after moderate vibration. It was observed that the ZL 30/50 fibers showed the greatest tendency for this clogging of the three fiber types while the ZL 60/80 showed the least.

Vibration of the fiber bed during infiltration helped greatly in preventing this clogging of the fiber bed. The ZL 30/50 fibers needed far more vibration than the other two fiber types to prevent clogging. The majority of the cylinders required no vibration for good infiltration. Only when vibration was applied is there a notation made in the figure titles. The decision to apply vibration was based on observations made during the infiltration process. When a slurry infiltrated the fiber with ease in the center of the fiber bed, there was confidence that the bed would be adequately infiltrated. When the slurry tended to accumulate in the center and begin to flow to the sides and then down the insides of the mold, clogging appeared to be taking place. If this occurred, a decision was made to vibrate the cylinder. Usually the vibration would facilitate infiltration and break up the clogging. There were only these few cases mentioned above where the sand and viscosity were excessive and where even vibration could not prevent the clogging of fibers. The figures also contain a notation indicating which cylinders were infiltrated when the slurry ran down the sides of the cylinder rather than through the center of the fiber bed.

There was little difference observed in the ability of the three fine-grained sands to infiltrate fiber beds. In the laboratory, the 50-mesh sand appeared to infiltrate only slightly easier than all four sand types tested. The coarser, washed plaster sand showed the most difficulty in infiltrating.

In conclusion, these observations demonstrated that great care is needed in proportioning sand slurries for successful fiber infiltration. In using sand it is desirable to keep the slurry as viscous as is practical in order to keep the sand grains in suspension. But the slurry must not be so viscous that clogging of the fiber bed occurs. Also, it has been observed that there is a practical limit of about 200-percent sand that can be introduced into a SIFCON slurry. Finally, fine-grained sands are preferable to conventional plaster sands. In fact, sands any coarser than masonry or plaster sands are not practical for SIFCON.

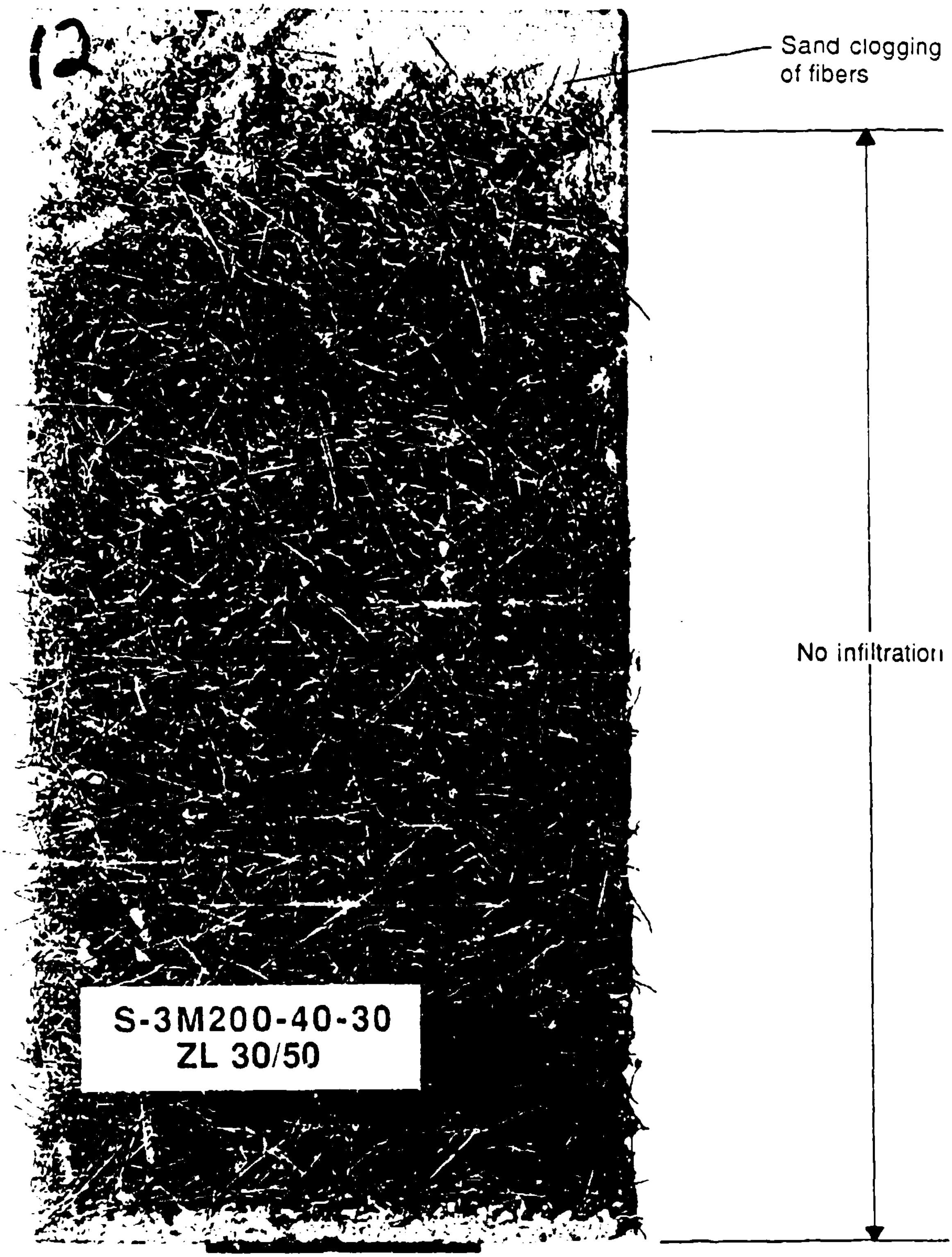


Figure 6. 30-mesh sand (200%) in fluid mix -- ZL 30/50 fibers, much vibration.

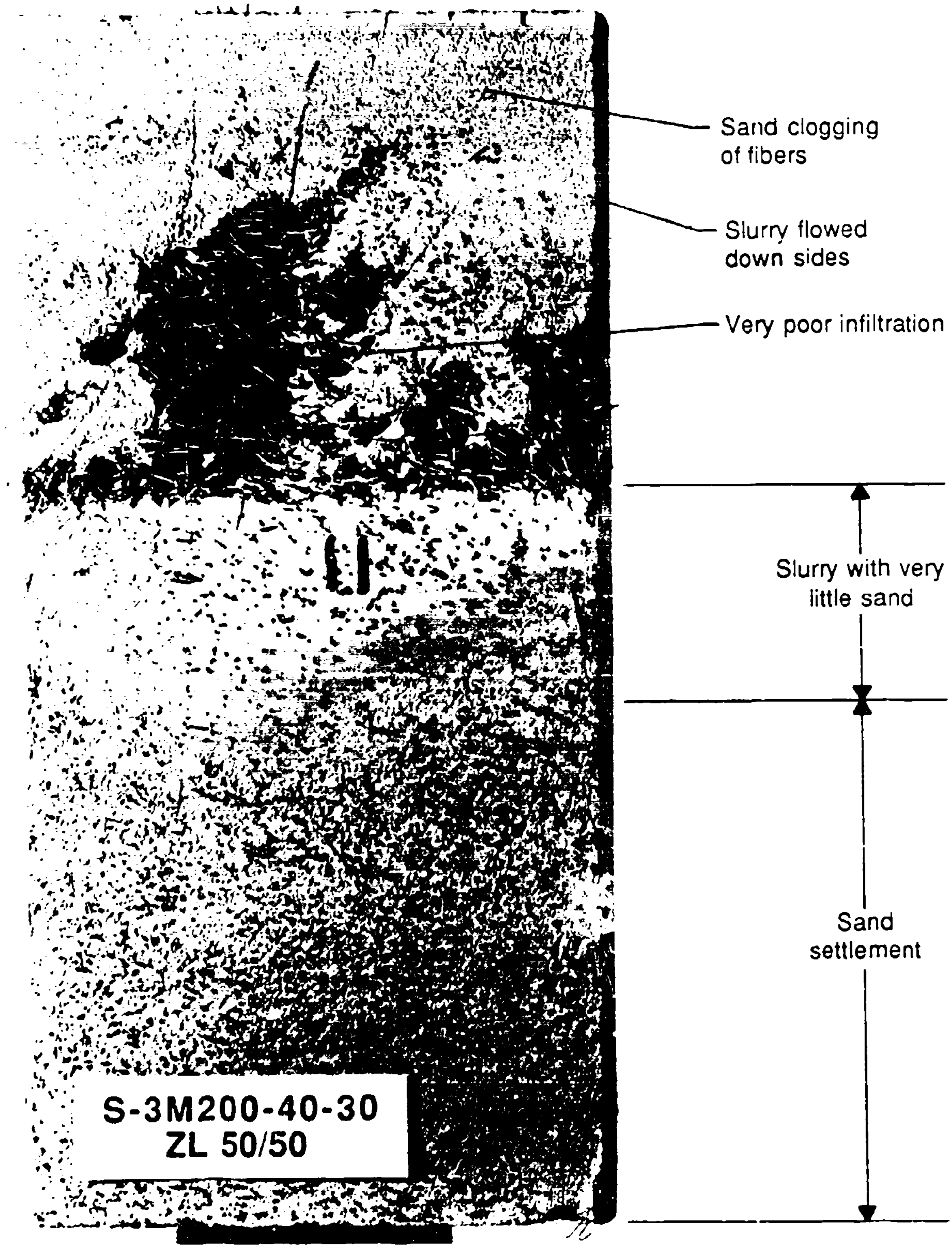


Figure 7. 30-mesh sand (200%) in fluid mix -- ZL 50/50 fibers, moderate vibration.

3.1.4 Slurry Compression Tests

Slurry cubes were molded for the majority of the sand slurry mixes of this phase of the study. Table 1 shows the mixes from which cubes were molded. From these cubes, uniaxial unconfined compression tests were performed. Table 5 presents the results of all these compression tests.

Table 5 groups the tests according to the three major fluidity groups: fluid mixes, moderately viscous mixes, and viscous mix. The variation percent next to the stress value represents the range of variation of the strength values for the entire set of the individual successful specimen tests. This value is calculated by taking the percent of the difference between the minimum and maximum values divided by the maximum. This value gives a relative indication of consistence within the set of tests. The settlement percent is a measure of the depth of sand settlement within the cubes with respect to the total specimen depth. The individual specimens were each visually inspected before testing to see the depth of this settlement. This depth was measured and then the value was divided by the total depth of the cube to obtain this percentage. There are two sets of averages. The averages at the right hand column relate to the individual mixes of sand types (i.e., S-5Mx-40-30). The average stress values represent those of the various sand percentages combined for each mix. The variation percentage represents the relative consistency of those same sand percentage stress values. The second set of averages, at the bottom of each table are averages of all the major mixes combined for each specific sand percentage (i.e., 50-percent sand). The variation percentage represents the relative consistency of these stress values.

The data are limited and somewhat inconsistent but show some trends. The major conclusion that can be drawn is that the use of fine-grained sands in these slurries does not significantly adversely affect the compressive strength. In most of the slurries, however, there tends to be a small decrease in slurry strength with the increase in sand percent. This is observed in the data representing all the sand types. The mix with viscosifier, however, showed data that indicated a slight increase in strength with increased sand percent. These increases or decreases are not major and may be partly explained in the scatter of test results that are typical of these types of tests. The differences in strength of the various sand types were even less varied. Actually, the variation percent for the slurry without any sand was greater than the variation percent of all those with different sand percent.

In conclusion, it seems that one can expect a slight decrease in the compressive strength of sand slurries with an increase in the percentage of sand. It appears that the type of sand has less effect

TABLE 5. Slurry compressive strength.

Fluid mixes (W/C+FA = 0.40)

Mix identification code	Ultimate compressive strength															
	0% sand		50% sand			100% sand			150% sand			200% sand			Average[c]	
	Var.,[a] %	Stress, lb/in²	Var., %	Stress, lb/in²	Sett.[b] %	Var., %	Stress, lb/in²	Sett., %	Var., %	Stress, lb/in²	Sett., %	Var., %	Stress, lb/in²	Sett., %	Var., %	Stress, lb/in²
S-5Mx-40-30	40.65	6220	10.62	5145	20	6.11	5405	45	5.12	5133	67	15.97	3971	87	36.16	5175
S-3Mx-40-30	8.33	5996	9.84	5351	37[d]	7.93	4932	47	12.78	4881	74	1.57	4415	84	26.37	5115
S-FBSx-40-30	8.54	4584	9.63	5224	25	2.06	5408		8.25	4642	70	1.76	4545	93	15.96	4881
SG-3Mx-40-30	14.85	4418	16.30	5251		20.30	4825		33.72	4824		16.34	5389		18.02	4941
S-SPx-40-30	23.8[illegible]	5779	15.00	5211	30	2.69	5653	51	6.05	4608	90				20.26	5313
Averages[c]	28.97	5399	3.85	5236	28	14.65	5245	48	10.23	4818	75	26.31	4580	88	8.13	5085

Moderately viscous mixes (W/C+FA = 0.35)

S-3Mx-35-30	8.94	6413	4.92	5578	32	2.75	5613	52	5.87	5379	73				16.12	5746
S-FBSx-35-30	3.77	6039	19.26	5476	33	13.03	5324	59	0.92	5163	89				14.51	5501
Averages	5.83	6226	1.83	5527	32	5.15	5469	55	4.02	5271	81				4.27	5623

Viscous mix (W/C+FA = 0.30)

S-5Mx-30-30	20.09	6765	21.04	7596		5.19	7763		19.59	5735					26.12	6965

[a] Var. (variation) = (minimum value - maximum value)/maximum value.

[b] Settlement percent (sand settling to the bottom of cube mold) = depth of settlement/ depth of cube specimen.

[c] Averages of the individual mixes of sand types.

[d] All values represent averages of three specimens except for S-FBS100-40-30 which represents an average of two specimens.

[c] Averages of the combination of mixes for each sand percentage.

on compressive strength than the percentage of sand. In interpreting these limited data it should be remembered that in many cases the cube specimens containing sand had settlement of the sand; therefore, the specimens were not homogeneous. This probably introduced some error in the test results. The tables show that when settlement occurred there was a greater percentage of settlement with a greater percentage of sand. This is what would be expected.

3.2 SELECTED SIFCON STUDY RESULTS

3.2.1 Infiltration Tests

It was learned from the first phase of this program that in sand slurries it is desirable for the slurry to be as viscous as possible to prevent sand settlement The slurry, however, must be fluid enough to produce good infiltration. One goal of this second phase was to find high-strength slurries with fluidities that would accomplish both these objectives. The procedures for producing such a slurry were described earlier in this report. It was also observed that fine-grained sands are the most practical for SIFCON slurries. Therefore, only the 50-mesh (four mixes) and 30-mesh (one mix) sands were used in this phase.

Table 6 shows the flow measurements for each slurry as well as the amount of vibration applied to each of the SIFCON slabs. Each slurry was made as viscous as practical. The range of flow measurements extended from 24-40 s at the initial measurement. The vibration required to assure infiltration was minimal for all slabs except those with ZL 30/50 fibers. The most viscous mix with an initial flow measurement of 40 s required 5 min of vibration for ZL 30/50 fibers and 1 min for the rest of the slabs. The mix with a small percentage of sand required no vibration for any slab. An observation made during the mixing and molding of specimens was that the use of microsilica seems to aid in holding the sand particles in suspension. This should be tested further because it is not certain whether it was the microsilica or simply the higher viscosity or a combination of both that produced this effect.

Observations were made on the test specimens that were removed from the slabs. All specimens revealed excellent infiltration. There were no voids and very few air bubbles observed. The sand distribution within the slab was also observed to be excellent. Negligible settlement of sand particles was noted.

Even though these data are limited, some conclusions seem evident. It is advantageous to keep fine-grained sand slurry mixes as viscous as practical. This not only helps keep sand particles in

TABLE 6. Selected SIFCON fluidity measurements.

Flow measurements

Mix identification code	Measurement time, T (T=x, min) 7	30	45	60	90	120	150	180
	Flow measurement, s							
S-5M150-15-42-0	24	24		28	32	34	36	40
S-5M100-10-37-0	40	40		45	57	82	104	
S-5M150-37-10	36		43	54	59	61	65	66
S-3M100-10-38-0	32	33	35	36	40	42	47	61
S-5M50-15-35-10	31	25	28	31	37	38	39	40

Note : The vertical lines within the table represent the slurry open time for the mixes. The horizontal lines simply join the vertical lines of these mixes.

Vibration

Mix identification code	Fiber type ZL 30/50	ZL 50/50	ZL 60/80	Aggr & ZL 60/80
	Vibration, min			
S-5M150-15-42-0	12	0	0	0
S-5M100-10-37-0	5	1	1	1
S-5M150-37-10	6	0	0	0
S-3M100-10-38-0	6	0.5	0.5	0.08
S-5M50-15-35-10	0	0	0	0

suspension in the slurry but keeps the W/C+FA ratio low, which results in higher SIFCON strength characteristics. A preliminary suggested range of flow measurements for these slurries should be between 25-40 s. Slurries at the lower end of this range will infiltrate easier, but also introduce the potential of settlement. Slurries at the upper end will ensure that the sand particles will remain in suspension but vibration may be required to produce proper infiltration. The ZL 30/50 fibers are the most difficult of the three types to infiltrate with viscous mixes. Vibration is probably needed whenever the ZL 30/50 fibers are used.

3.2.2 SIFCON Compressive Tests

The compressive strength of SIFCON containing fine-grained sands is of special interest. The addition of sands to SIFCON slurries is advantageous only if the sand does not adversely affect the SIFCON strength. Therefore, mixes using sand were designed, and specimens were prepared that would produce relatively high-strength SIFCON. Core specimens were removed from the SIFCON slabs that were described earlier. Strength comparisons were also made between the three fiber types that were used.

Individual stress versus strain plots were generated for all these tests. These are contained in Appendix B (Figures B1 through B20). Table 7 summarizes the ultimate strengths for all these plots. The table shows that relatively high-strength SIFCON is possible using relatively high percentages of fine-grained sands. The strengths are at levels that would be expected of similar slurries not containing sands. In fact, there may even be an enhancing of the strength with the presence of the sand. The strengths ranged from 18,889 to 25,724 lb/in^2 for ZL 30/50 fiber with a high-density fiber bed to 13,076 to 17,851 lb/in^2 for ZL 50/50 fiber with a low-density fiber bed. As would be expected, the greater the percentage of fiber in the bed, the higher the strengths produced due to the additional reinforcement of the fibers.

3.2.3 Aggregate and Fiber Combination

Since it has been shown that it is advantageous to use fine-grained sands in SIFCON, preliminary consideration was given to the use of concrete aggregate as well. A major problem in using aggregate is getting the aggregate into the fiber bed. For the purpose of this study, the aggregate was preplaced by hand in conjunction with the fiber.

TABLE 7. Selected SIFCON compressive strength.

Mix identification code	Ultimate compressive strength									
	Slurry		Fiber type							
			ZL 30/50		ZL 50/50		ZL 60/80		Aggregate & ZL 60/80	
	Stress, lb/in^2	Variation, %	Stress, lb/in^2	Variation, %	Stress, lb/in^2	Variation, %	Stress, lb/in^2	Variation, %	Stress, lb/in^2	Variation, %
S-5M150-15-42-0	11,209	18.61	25,724	9.04	17,851	5.42	18,448	13.77	16,968	12.63
S-5M100-10-37-0	10.563	6.88	22,617	8.83[a]	16,062	6.34	17,833	8.96	19,046	4.85
S-5M150-37-10	7,220	8.06	19,033	17.15	13,076	6.50	14,070	13.64[a]	12,783	19.11
S-3M100-10-38-0	10,112	15.65	21,661	15.17[a]	16,193	9.60	16,451	12.52	15,301	12.99
S-5M50-15-35-10	10,661	17.32	18,889	17.53	15,000	5.69	15,453	10.72	14,925	4.61

Note: All test values represent averages of three test specimens.

[a] All SIFCON values represent averages of five test specimens except S-5M100-10-37-0 (ZL 30/50) and S-5M150-37-10 (ZL 60/80) which had four test specimens and S-3M100-10-38-0 (ZL 30/50) which had three test specimens.

The proportions and distribution of these two ingredients were visually estimated as the placement progressed. The final proportions were calculated from actual fiber and aggregate weights placed in the mold. Table B1 contains these weights and proportions.

The infiltration of the combination of aggregate and fiber bed showed no noticeable difference from that of the slab containing only the same fiber type. Table 5 shows that the needed vibration for infiltration was the same as that of the slab containing only the same fiber type.

Comparing the ultimate strength values in Table 6 of the combination of aggregate and fiber with that of only the fiber show little difference. Of the five different mixes, four strength results of the combination were only slightly lower while one was even higher than that of the slab containing only the same fiber type.

In conclusion, these few test results show some advantage of using concrete aggregate in SIFCON. If the practical problems of preplacing the aggregate can be overcome, it appears that the use of aggregate may introduce additional cost saving without significantly affecting the strength properties.

4.0 SIFCON COST STUDY

4.1 INTRODUCTION

It has been demonstrated that the use of sands in SIFCON slurries is not a simple matter. A major advantage of using sand in SIFCON in addition to strength enhancement would be significant cost savings. This section presents the cost savings possible with the use of sands and aggregate.

This study was performed using the mixes from the selected SIFCON study phase of the report. The proportions of these mixes and their final ultimate strengths were determined in that phase of the study. These proportions and strengths were used to calculate the cost and strength comparisons. Unit costs were obtained from local or national materials suppliers. They reflect 1987 industry unit prices for orders of relatively small size.

4.2 MATERIAL COST

Table B2 contains the detailed cost information. Table 8 is a summary of Table B2. The individual tables for each mix have two parts. The top portion presents the cost for the specific mix that was actually made. The bottom portion shows the costs for a calculated mix omitting the sand and aggregate but retaining the same mix proportions for the rest of the ingredients. Both portions present the costs per cubic yard of each individual ingredient and a total summation of these costs. The top portion of each table also presents the actual average ultimate strength results for each specific slurry and SIFCON. From the ultimate strength results and the total cost values a strength and cost factor can be calculated. This strength/dollar factor gives a relative indication of the cost efficiency of the different SIFCON fibers.

It is evident from the tables that the largest percentages of the costs are found in the cost of fibers (68-87 percent). The remaining cost is made up by the slurry. For the majority of SIFCON costs, the most flexibility lies in the percentage of fibers used. Obviously SIFCON with the higher percentages of fibers was more expensive. For the fiber types tested, there was a tendency for higher strengths with higher fiber percentages. The range of costs for these five SIFCON groups was $846 for SIFCON with 11 percent of ZL 30/50 fibers to $487 for SIFCON with 6 percent of ZL 60/80 fibers with aggregate interspersed. The strength/dollar factor varied from mix to mix. Within each mix, this factor was highest for ZL 50/50 fiber and the ZL 60/80 fiber with aggregate interspersed.

TABLE 8. SIFCON material costs summary.

Unit costs

Material	Units	Cost
Cement	$/lb	0.0530
Fly ash	$/lb	0.0225
Sand	$/lb	0.0100
Aggregate	$/lb	0.0060
Microsilica (EMS 960)	$/lb	0.0800
Superplasticizer	$/gal	7.5000
Fiber	$/lb	0.4800

Efficiency factor =

$$\frac{(SIF - Slu)/Slu}{Fib}$$

Where : SIF = SIFCON strength
Slu = Slurry strength
Fib = Steel fiber percent

Material costs for selected SIFCON mixes

S-5M150-15-42-0

Material	Material costs, $/cu yd				
	Slurry	ZL30/50 11%	ZL50/50 6%	ZL60/80 8.50%	Agg. & ZL60/80 6.06%
Total cost, $	133.45	817.31	506.46	661.89	496.36
Strength, lb/in^2	11,209	25,724	17,851	18,448	16,968
Strength/dollar, lb/in^2/$	84	31	35	28	34
Efficiency factor		11.8	9.9	7.6	8.5
Same mix omitting the sand and aggregate					
Total cost, $	197.54	874.35	566.71	720.53	720.53
Savings, %	32.44	6.52	10.63	8.14	31.11

S-5M100-10-37-0

Total cost, $	141.54	824.52	514.07	669.30	540.68
Strength, lb/in^2	10,563	22.617	16,062	17,833	19,000
Strength/dollar, lb/in^2/$	75	27	31	27	35
Efficiency factor		10.4	8.7	8.1	12.1
Same mix omitting the sand and aggregate					
Total cost, $	193.13	870.43	562.57	716.50	716.50
Savings, %	26.71	5.27	8.62	6.59	24.54

TABLE 8. Concluded.

S-5M150-37-10

Material	Material costs, $/cu yd				
	Slurry 0%	ZL30/50 11%	ZL50/50 6%	ZL60/80 8.50%	Agg. & ZL60/80 6.06%
Total cost, $	120.05	805.39	493.87	649.63	487.27
Strength, lb/in^2	7,220	19,033	13,076	14,070	12,783
Strength/dollar, lb/in^2 /$	60	24	26	22	26
Efficiency factor		14.9	13.5	11.2	12.7
Same mix omitting the sand and aggregate					
Total cost, $	176.56	855.69	546.99	701.34	701.34
Savings, %	32.01	5.88	9.71	7.37	30.52

S-3M100-10-38-0

Total cost, $	139.96	823.11	512.59	667.85	478.77
Strength, lb/in^2	10,112	21,661	16,193	16,451	15,301
Strength/dollar, lb/in^2 /$	72	26	32	25	32
Efficiency factor		10.4	10.0	7.4	9.0
Same mix omitting the sand and aggregate					
Total cost, $	189.85	867.51	559.48	713.49	713.49
Savings, %	26.28	5.12	8.38	6.40	32.90

S-5M50-15-35-10

Total cost, $	165.44	845.79	536.54	691.17	531.80
Strength, lb/in^2	10,661	18,889	15,000	15,453	14,925
Strength/dollar, lb/in^2 /$	64	22	28	22	28
Efficiency factor		7.0	6.8	5.3	6.4
Same mix omitting the sand and aggregate					
Total cost, $	193.94	871.15	563.32	717.23	717.23
Savings, %	14.63	2.91	4.75	3.63	25.85

Significant savings can be gained by the use of sands and aggregates. The tables compare the detailed costs for the mixes with and without the use of sand and aggregate. The tables compare the percent savings realized with the use of the sand and/or aggregate compared to the same mix with the sand and aggregate omitted. The percent savings is calculated by subtracting the total cost of the mixes containing the sand and/or aggregate from the cost of mixes without them and then dividing by the cost of the mix without sand and/or aggregate. The savings are greatest when sand and aggregate are both used. With a high percentage of sand and some aggregate, the savings are 31 percent. Even with a low percentage of sand and some aggregate, the savings are 26 percent. Savings between 6-11 percent can be realized using only a high percentage of sand. Sand reduces costs because it replaces more expensive slurry ingredients such as cement. The small quantity of aggregate significantly reduces costs because it not only replaces the more expensive slurry ingredients but it also reduces the percentage of the very expensive fiber by approximately 2 percent. This reduction in fiber percent also accounts for the reduction in strength when comparing the strengths of the fiber with the aggregate and the same fiber without aggregate.

In conclusion, these cost studies demonstrate realistic material costs for high-strength SIFCON. They show that the fibers are by far the most costly ingredient. They also show that sand and aggregates in SIFCON significantly reduce the material costs.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 MAJOR CONCLUSIONS

This preliminary program demonstrated that sands can be successfully added to SIFCON slurries and that certain advantages can be gained from their use. It was also demonstrated that to ensure successful use, careful proportioning and quality control is needed. Several conclusions can be drawn from these results. Table 9 summarizes the specific conclusions of this program.

This study demonstrated that sands can be used successfully in SIFCON only under restricted conditions. First, only fine-grain sands should be used. The sands that appear to be best suited for SIFCON use are those sands with a maximum grain size passing the No. 30 sieve. Such sands are commercialy available. In some applications, plaster or masonry sands could also be used, but they should be considered marginal. It appears that the maximum quantity of sands practical to use is between 150 to 200 percent with respect to the cement. Second, sand slurry fluidity is extremely important. If the sand slurry is too fluid, sand particles tend to settle out of the mix. If the slurry is too viscous, infiltration problems occur; therefore, there is a narrow band of fluidity that is workable. This study shows that sand slurries with flow measurements between 25 to 40 s are recommended. Third, characteristics of the type of fiber to be used should be understood. The denser the fiber bed, which is generally indicated by the fiber percent, the greater the resistance of that bed to infiltration by sand slurries; therefore, vibration of fiber beds during slurry infiltration should be performed if denser fiber beds are used. For these fiber beds one should also design sand slurries with a little more fluidity than for less dense fiber beds.

This study demonstrates definite advantages in using sands and even aggregates in SIFCON. The main advantage involves significant cost savings. By adding mass to the matrix, the sand and/or aggregates in a mix replace much more expensive ingredients. The use of sands in slurries can produce savings in the 5 to 11 percent range. This is significant when fibers contribute 68 to 87 percent of the cost of SIFCON. The addition of relatively small quantities of aggregate in the fiber bed affords savings of 25 to 33 percent. This high cost savings results because the aggregate replaces the more expensive slurry ingredients and the very expensive fibers. When the fiber percent is reduced, lower strengths should be expected. Another advantage in the use of sands is that there appears to be an enhancing rather than a lowering of the SIFCON strength properties. At worst, sands do not significantly adversely affect the strength properties. Even the aggregate, that lowers fiber density and therefore lowers strength, does not lower the strength of the SIFCON below that SIFCON with the same fiber percentage without aggregate.

TABLE 9. Summary of conclusions.

Tests or observations	Variables as variables increase or vary	Effects, limits, or conclusions
Infiltration study		
Fluidity		
Flow measurements	W/C+FA	Viscosity decreases
	Sand, %	Viscosity increases
	Time	Viscosity increases
	Sand type	Inconclusive
	Viscosifier	Viscosity increases
Open time	Viscosity	Open time decreases
Penetration tests	W/C+FA	Penetration % increases
	Fiber density	Penetration % decreases
	Sand type	Inconclusive
Settlement observations	Fiber density	Sand entrapment increases
	Fiber density	Infiltration difficulty increases
	Viscosity	Settlement decreases
	Viscosity	Infiltration difficulty increases
	Sand, %	Maximum between 150-200%
Slurry compression	Sand, %	Slight decrease or inconclusive
	Sand type	Inconclusive
Selected SIFCON study		
Infiltration		
Flow		Recommend between 25-40 s
Vibration		Recommend for ZL 30/50 fibers
Compression tests		
Slurry containing sand		Enhanced strength
Aggregate and fiber		
Infiltration		Same as without aggregate
Compression tests		Strength reduction
SIFCON cost study		
100-150 percent sand		5-11 percent savings
36-57 percent aggregate		25-33 percent savings due mainly to the fiber reduction

5.2 RECOMMENDATIONS

This program was only a preliminary investigation. Therefore it is recommended that the conclusions obtained should not only be verified but expanded. The work done involved a very small data base. This should be enlarged with further testing. Only three fiber types and only four sand types were considered in the program. These parameters could be expanded. The penetration test that was developed needs refinement for more reliability.

The use of aggregate in fiber beds was only touched on. The great potential for cost savings would warrant much more work in the use of aggregate.

It appears that microsilica not only increases SIFCON strength but may have helped keep sand particles in suspension. Verification of this would encourage the use of microsilica in SIFCON.

5.3 CONCLUSION

Another step has been taken in not only defining the nature of SIFCON but in making it a more practical construction material. The conclusions of this report are perhaps the most encouraging to date concerning SIFCON potential.

REFERENCES

1. Schneider, Bruce, and Mondragon, Ray, **Design and Construction Techniques For SIFCON,** New Mexico Engineering Research Institute, Albuquerque, N.M., WA2-57, May 1988.

2. Mondragon, Ray, **Development of Material Properties for Slurry Infiltrated Fiber Concrete (SIFCON) - Compressive Strength**, AFWL-TR-86-43, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico, December 1985.

3. Mondragon, Ray, **Development of Material Properties for Slurry Infiltrated Fiber Concrete (SIFCON) - Flexural Strength**, AFWL-TR 87-79, Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico.

APPENDIX A
SAND SLURRY INFILTRATION STUDY

This appendix contains the mix designs (Table A1), flow measurements (Table A2), and sand distribution photographs (Figures A1 through A84) for the sand slurry infiltration phase of this program.

TABLE A1. Sand slurry infiltration study mix designs.

Constants:	Fly ash/cement:	30/70
	Superplasticizer:	30 oz/100 wt
Variables:	Sand types:	50 mesh, 30 mesh, fine blasting, washed plaster
	Sand/cement:	0 to 200 percent
	Water/cement + fly ash:	0.30, 0.35, 0.40
	Fiber types:	ZL 30/50, ZL 50/50, ZL 60/80

Mix proportions:

Fluid mixes (W/C+FA = 0.40)

<table>
<tr><th>Mix identification code</th><th>Sand type</th><th>Slurry, lb</th><th>Cement, lb</th><th>Fly ash, lb</th><th>Water, lb</th><th>Superplasticizer, cm^3</th><th>Sand, lb</th><th>Sand/cement, %</th></tr>
<tr><td>S-5Mx-40-30</td><td>50 mesh</td><td></td><td>154.00</td><td>66.00</td><td>88.00</td><td>1950</td><td></td><td></td></tr>
<tr><td>S-5M0-40-30</td><td></td><td>20</td><td>(9.84)</td><td>(4.22)</td><td>(5.62)</td><td>(125)</td><td>0.00</td><td>0</td></tr>
<tr><td>S-5M50-40-30</td><td></td><td>80</td><td>(39.35)</td><td>(16.87)</td><td>(22.49)</td><td>(499)</td><td>19.68</td><td>50</td></tr>
<tr><td>S-5M100-40-30</td><td></td><td>90</td><td>(44.27)</td><td>(18.97)</td><td>(25.30)</td><td>(561)</td><td>44.27</td><td>100</td></tr>
<tr><td>S-5M150-40-30</td><td></td><td>60</td><td>(29.52)</td><td>(12.65)</td><td>(16.87)</td><td>(374)</td><td>44.27</td><td>150</td></tr>
<tr><td>S-5M200-40-30</td><td></td><td>54</td><td>(26.56)</td><td>(11.38)</td><td>(15.18)</td><td>(337)</td><td>53.13</td><td>200</td></tr>
<tr><td>S-3Mx-40-30</td><td>30 mesh</td><td colspan="7" rowspan="3">All ingredients except the sand, all parameters, weights, measures, and percentages are identical to mixes S-5Mx-40-30 above.

Note : Mix SG-3Mx-40-30 contains 4.4 lb (2%) bentonite also.</td></tr>
<tr><td>S-FBSx-40-30</td><td>Fine blasting sand</td></tr>
<tr><td>SG-3Mx-40-30</td><td>30 mesh</td></tr>
<tr><td>S-SPx-40-30</td><td rowspan="5">Washed plaster sand</td><td></td><td>128.00</td><td>54.86</td><td>73.14</td><td>1620</td><td></td><td></td></tr>
<tr><td>S-SP0-40-30</td><td>20</td><td>(9.84)</td><td>(4.22)</td><td>(5.62)</td><td>(125)</td><td>0.00</td><td>0</td></tr>
<tr><td>S-SP50-40-30</td><td>80</td><td>(39.35)</td><td>(16.87)</td><td>(22.49)</td><td>(499)</td><td>19.68</td><td>50</td></tr>
<tr><td>S-SP100-40-30</td><td>90</td><td>(44.27)</td><td>(18.97)</td><td>(25.30)</td><td>(561)</td><td>44.27</td><td>100</td></tr>
<tr><td>S-SP150-40-30</td><td>60</td><td>(29.52)</td><td>(12.65)</td><td>(16.87)</td><td>(374)</td><td>44.27</td><td>150</td></tr>
<tr><td>S-5M100-40-30 B</td><td>50 mesh</td><td></td><td>17.00</td><td>7.28</td><td>9.92</td><td>215</td><td>16.80</td><td>100</td></tr>
<tr><td>S-3M100-40-30 B</td><td>30 mesh</td><td colspan="7" rowspan="3">All ingredients except the sand, all parameters, weights, measures, and percentages are identical to mix S-5M100-40-30 B above.</td></tr>
<tr><td>S-FBS100-40-30 B</td><td>Fine blasting sand</td></tr>
<tr><td>S-SP100-40-30 B</td><td>Washed plaster sand</td></tr>
</table>

Note : All numbers in parentheses represent calculated values.

TABLE A1. Concluded.

Moderately viscous mixes (W/C+FA = 0.35)

Mix identification code	Sand type	Slurry, lb	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	Sand, lb	Sand/cement, %
S-3Mx-35-30	30 mesh		140.00	60.00	70.00	1775		
S-3M0-35-30		20	(10.20)	(4.37)	(5.10)	(129)	0.00	0
S-3M50-35-30		80	(40.79)	(17.48)	(20.39)	(517)	20 39	50
S-3M100-35-30		90	(45.89)	(19.67)	(22.94)	(581)	45.89	100
S-3M150-35-30		60	(30.59)	(13.11)	(15.30)	(388)	45.89	150
S-FBSx-35-30	Fine blasting sand	All ingredients except the sand, all parameters, weights, measures, and percentages are identical to mixes S-3Mx-35-30 above.						
S-5M100-35-30 B	50 mesh		18.00	7.71	9.22	228	17.78	100
S-3M100-35-30 B	Fine blasting sand	All ingredients except the sand, all parameters, weights, measures, and percentages are identical to mix S-5M100-35-30 B above.						

Viscous mix (W/C+FA = 0.30)

Mix identification code	Sand type	Slurry, lb	Cement, lb	Fly ash, lb	Water, lb	Superplasticizer, cm^3	Sand, lb	Sand/cement, %
S-5Mx-30-30	50 mesh		140.00	60.00	60.00	1775		
S-5M0-30-30		20	(10.58)	(4.54)	(4.54)	(134)	0.00	0
S-5M50-30-30		80	(39.35)	(16.87)	(22.49)	(499)	21.17	50
S-5M100-30-30		90	(44.27)	(18.97)	(25.30)	(561)	47.62	100
S-5M150-30-30		60	(29.52)	(12.65)	(16.87)	(374)	47.62	150

TABLE A2. Flow measurements.

Fluid mixes (W/C+FA = 0.40)

Mix identification code	S-5Mx-40-30				
	Sand percentage				
Time, min[a]	0	50	100	150	200
	Flow measurement, s				
6	13				
31					34
35				16	
38			16		
42		15			
46	14				
61					38
65				22	
67			17		
70		15			
72	13				
94					42
96				23	
99			16		
102		15			
105	14				
123					44
125				24	
128			17		
130		20			
132	14				
152					46
154				24	
156			17		
158		15			
160	15				
182					51
184				26	
186			18		
188		15			
190	15				
212					53
214				26	
216			18		
219		16			
221	15				
243					57
245				29	
247			21		
250		16			
252	15				

	S-3Mx-40-30				
	Sand percentage				
Time, min	0	50	100	150	200
	Flow measurement, s				
6	13				
31					41
40				18	
46			18		
50		17			
55	18				
64					49
70				31	
73			18		
80		15			
82	15				
92					55
95				26	
98			14		
102		17			
105	16				
122				27	
127			20		
130		17			
133	17				
151				29	
155			21		
158		17			
161	17				
183				31	
187			23		
190		17			
192	17				
213				31	
217			23		
220		18			
223	18				
243				34	
246			25		
249		18			
252	18				

	S-5M100-40-30 B	S-3M100-40-30 B
	Sand percentage	
Time, min	100	
	Flow measurement, s	
9	17	16
30	17	17
60	18	18
90	19	19
120	20	19
150	21	19

	S-FBS100-40-30 B	S-SP100-40-30 B
	Sand percentage	
Time, min	100	
	Flow measurement, s	
9	16	15
30	17	15
60	18	15
90	20	16
120	20	17
150	20	

[a] Specific times when test was taken with respect to the initial mix start time (T = 0).

TABLE A2. Continued.

Mix identification code	S-FBSx-40-30				
	Sand percentage				
Time, min	0	50	100	150	200
	Flow measurement, s				
8	12				
31					33
33				20	
35			15		
36		14			
38	12				
62					35
63				20	
65			16		
66		13			
68	12				
92					37
94				21	
96			16		
98		19			
100	13				
125					41
127				22	
129			17		
130		15			
132	14				
155					46
158				23	
159			17		
160		15			
162	13				
181					50
182				25	
184			17		
185		16			
186	14				
211					53
213				26	
214			18		
216		16			
217	14				
242					57
245				28	
247			18		
248		17			
250	15				

S-SPx-40-30					
	Sand percentage				
Time, min	0	50	100	150	200
	Flow measurement, s				
8	12				
31				26	
35			17		
38		15			
41	12				
61				22	
63			17		
65		16			
66	13				
91				24	
93			18		
96		16			
98	14				
120				26	
123			20		
125		18			
128	15				
151				27	
153			21		
155		18			
157	16				
181				29	
183			23		
186		19			
188	16				
210				31	
213			24		
215		19			
217	17				
242				34	
244			27		
246		21			
249	18				

SG-3Mx-40-30					
	Sand percentage				
Time, min	0	50	100	150	200
	Flow measurement, s				
8	14				
33					49
35				12	
38			20		
40		18			
42	17				
62					53
64				30	
66			21		
68		18			
70	18				
96					68
98				36	
99			22		
101		20			
103	19				
122					69
123				38	
126			40		
128		23			
130	21				
151					79
154				42	
157			27		
159		23			
160	22				
182				48	
184			30		
185		25			
187	25				
214				55	
216			32		
217		28			
220	30				
243				61	
245			34		
246		31			
248	32				

TABLE A2. Concluded.

Moderately viscous mixes (W/C+FA = 0.35)

Mix identification code	S-3Mx-35-30				
	Sand percentage				
Time, min	0	50	100	150	200
	Flow measurement, s				
8	14				
31				25	
32			17		
34		16			
36	14				
62				26	
63			19		
64		15			
66	15				
91				29	
94			22		
96		16			
98	15				
121				33	
123			24		
125		18			
127	17				
151				35	
153			25		
155		18			
157	17				
181				38	
183			27		
185		19			
187	18				
211				40	
213			28		
216		20			
218	18				
240				44	
242			29		
244		20			
246	19				

	S-FBSx-35-30				
	Sand percentage				
Time, min	0	50	100	150	200
	Flow measurement, s				
8	13				
31				29	
32			18		
34		15			
36	14				
61				30	
64			18		
65		15			
66	14				
91				33	
93			20		
95		17			
96	14				
120				35	
121			20		
123		17			
124	15				
152				45	
154			21		
155		18			
156	15				
182				44	
184			23		
186		19			
187	16				
211				47	
213			22		
214		20			
216	18				
241				54	
243			24		
245		21			
247	19				

	S-5M100-35-30	S-3M100-35-30 B
	Sand percentage	
Time, min	100	
	Flow measurement, s	
9	32	30
30	37	37
60	50	57
90	97	167
120	149	

Viscous mixes (W/C+FA = 0.30)

Mix identification code	S-5Mx-30-30				
	Sand percentage				
Time, min	0	50	100	150	200
	Flow measurement, s				
8	54				
36				no	
39			95		
43		94			
49	no				

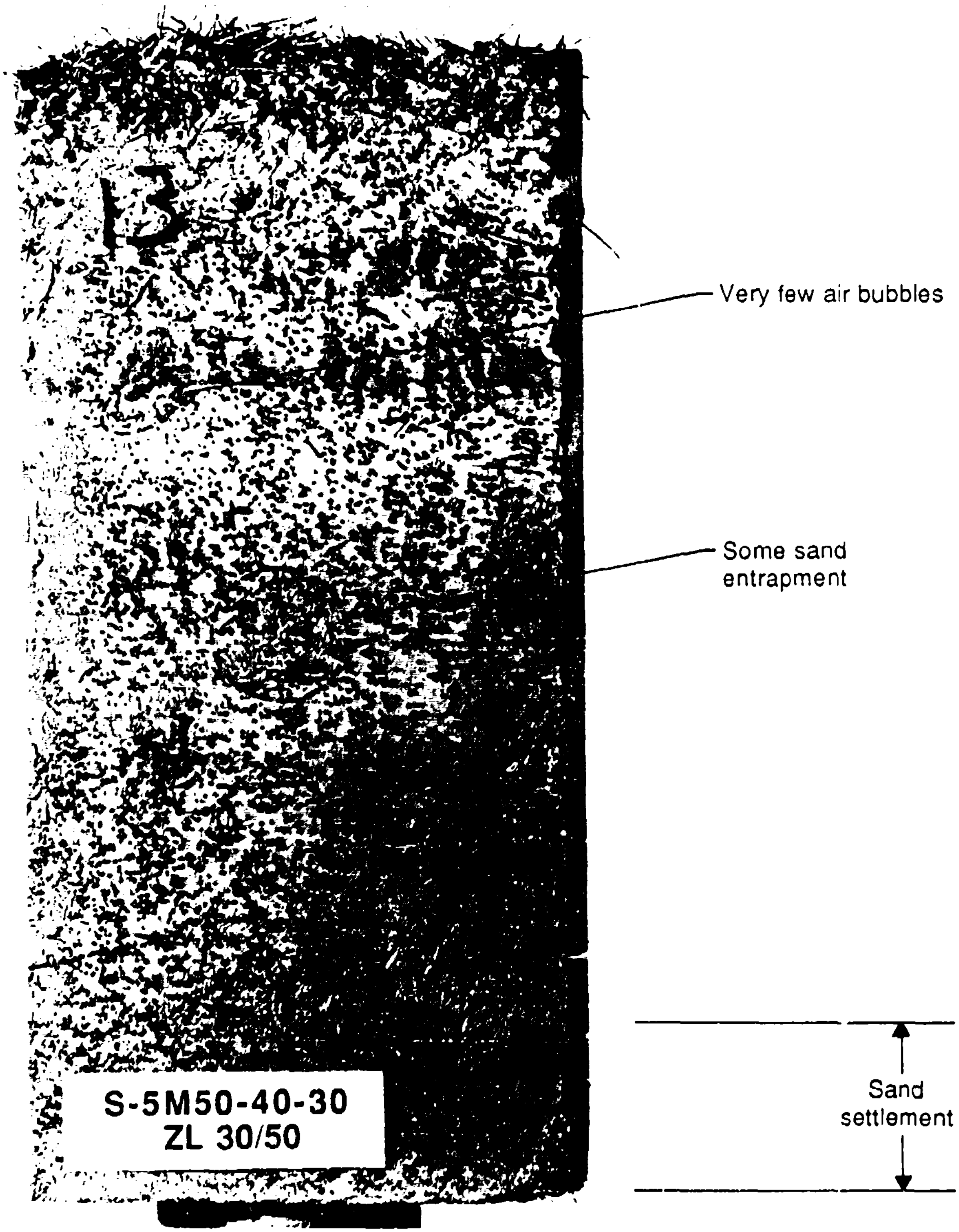


Figure A1. 50-mesh sand (50%) in fluid mix -- ZL 30/50 fibers.

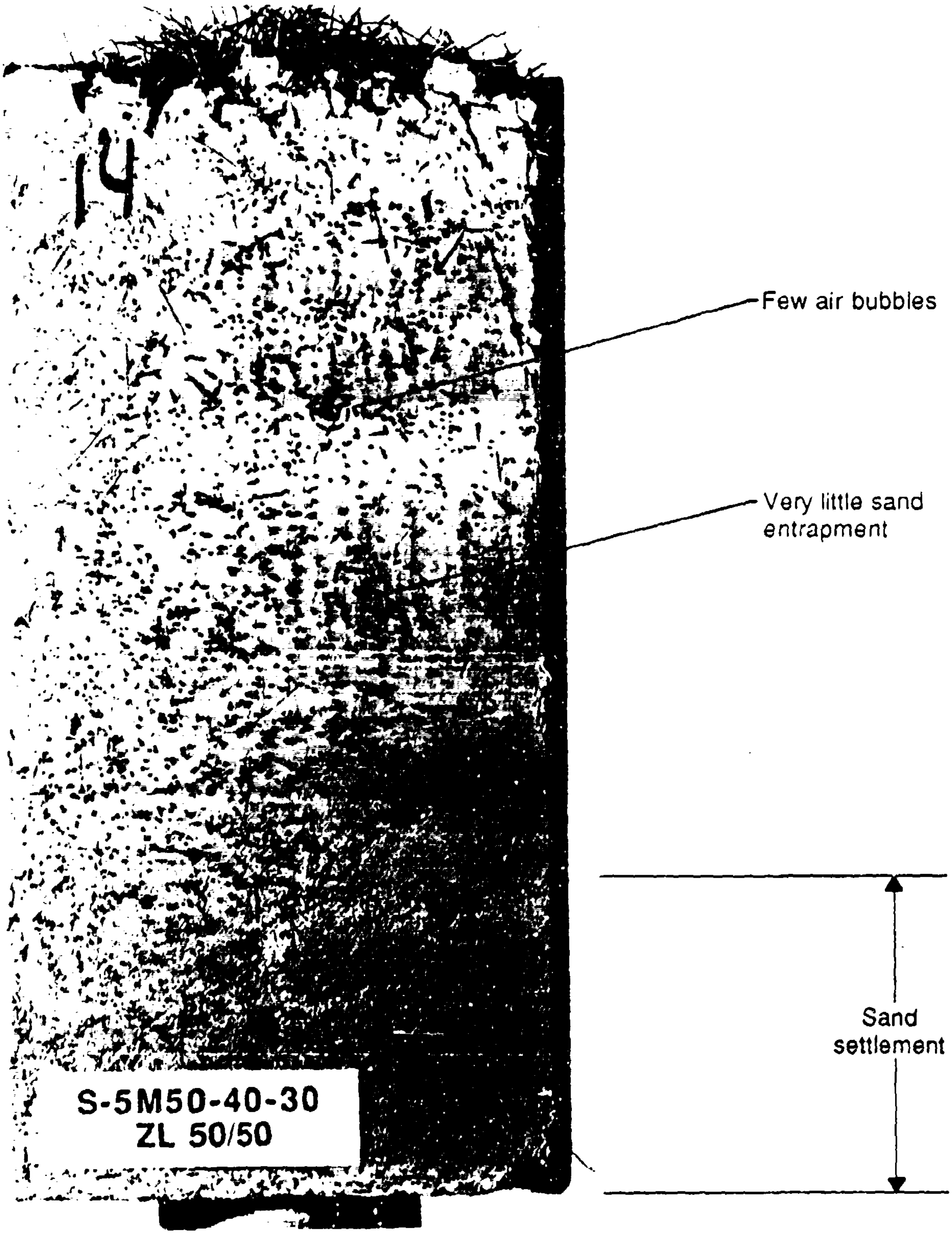


Figure A2. 50-mesh sand (50%) in fluid mix -- ZL 50/50 fibers.

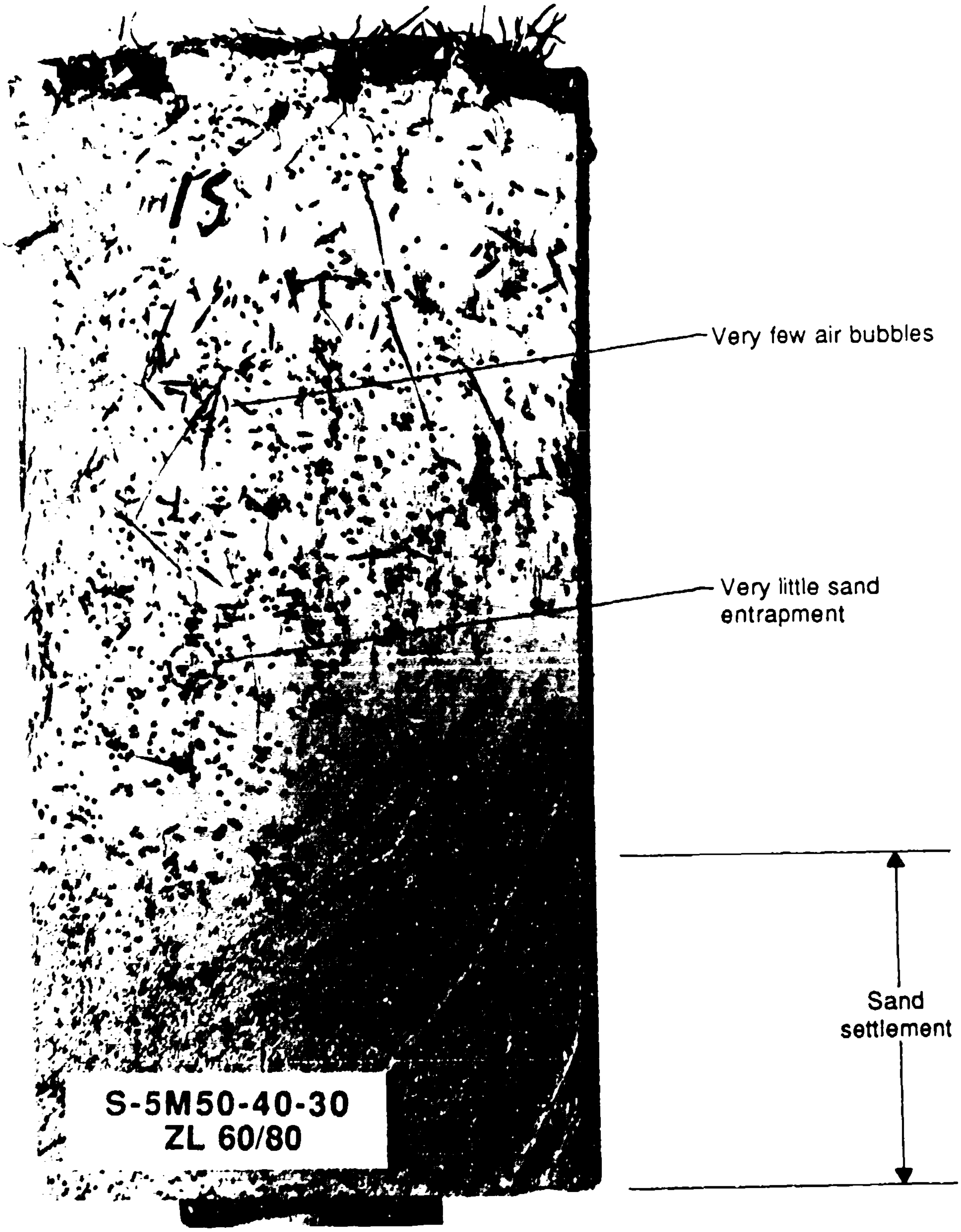


Figure A3. 50-mesh sand (50%) in fluid mix -- ZL 60/80 fibers.

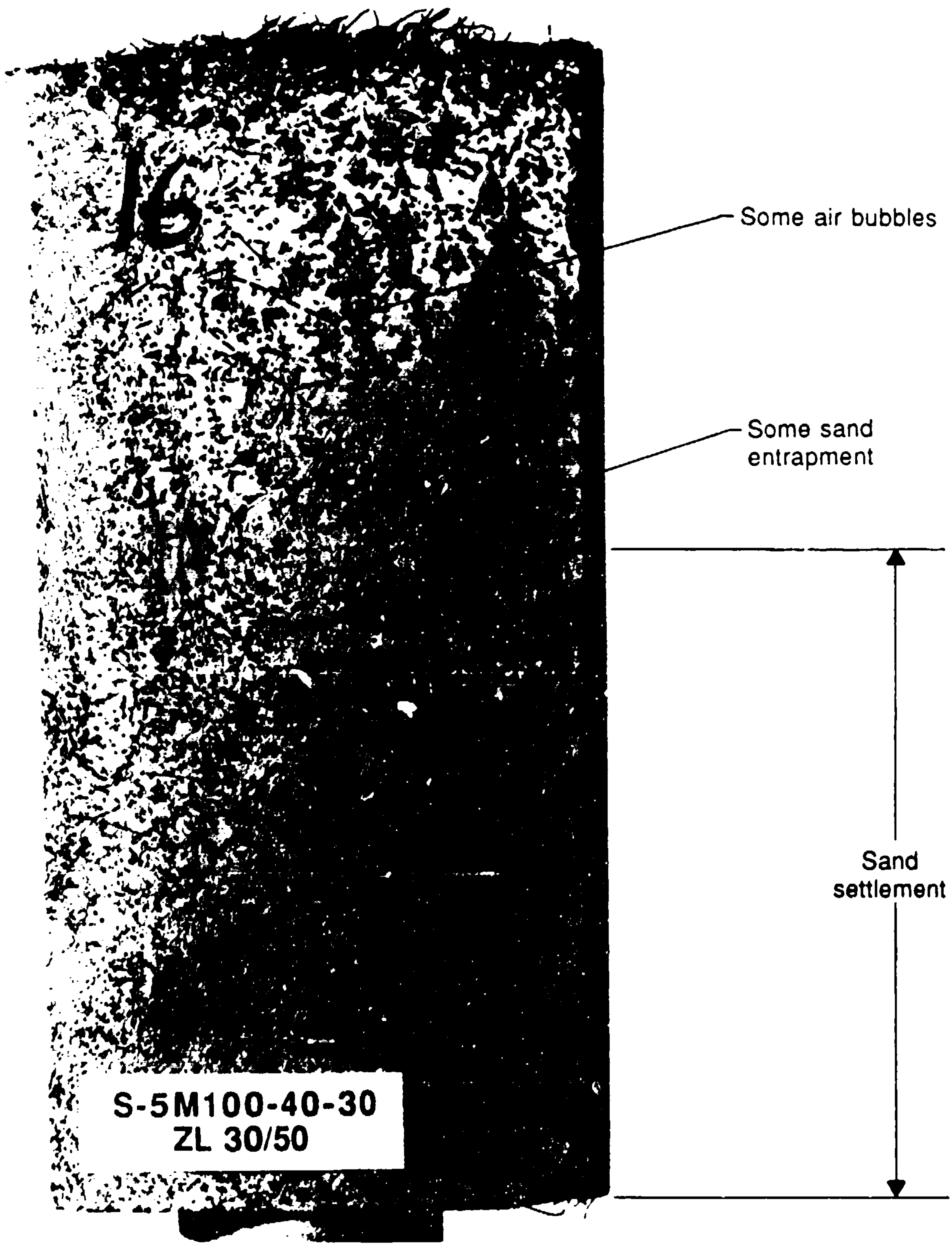


Figure A4. 50-mesh sand (100%) in fluid mix -- ZL 30/50 fibers.

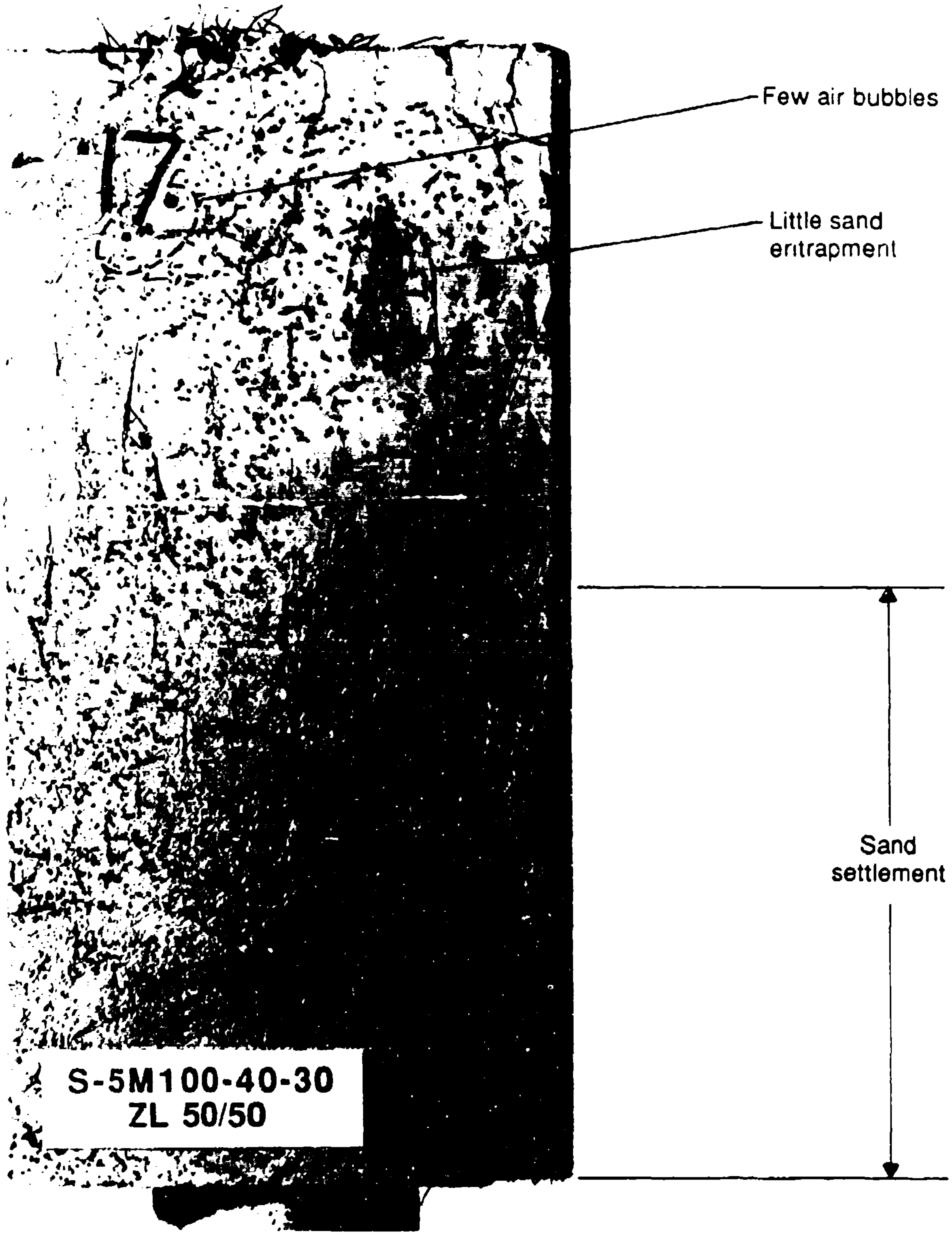


Figure A5. 50-mesh sand (100%) in fluid mix -- ZL 50/50 fibers.

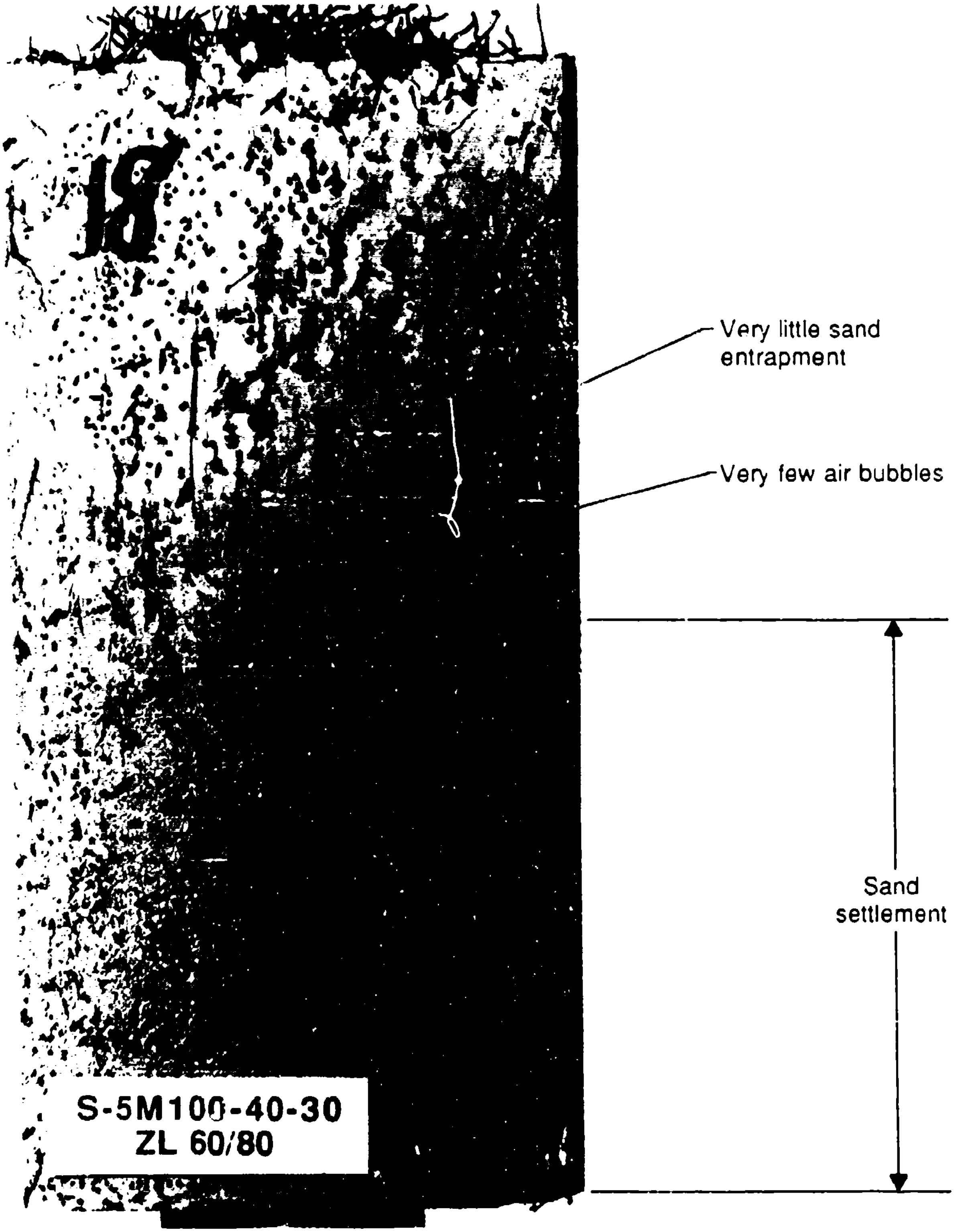


Figure A6. 50-mesh sand (100%) in fluid mix -- ZL 60/80 fibers.

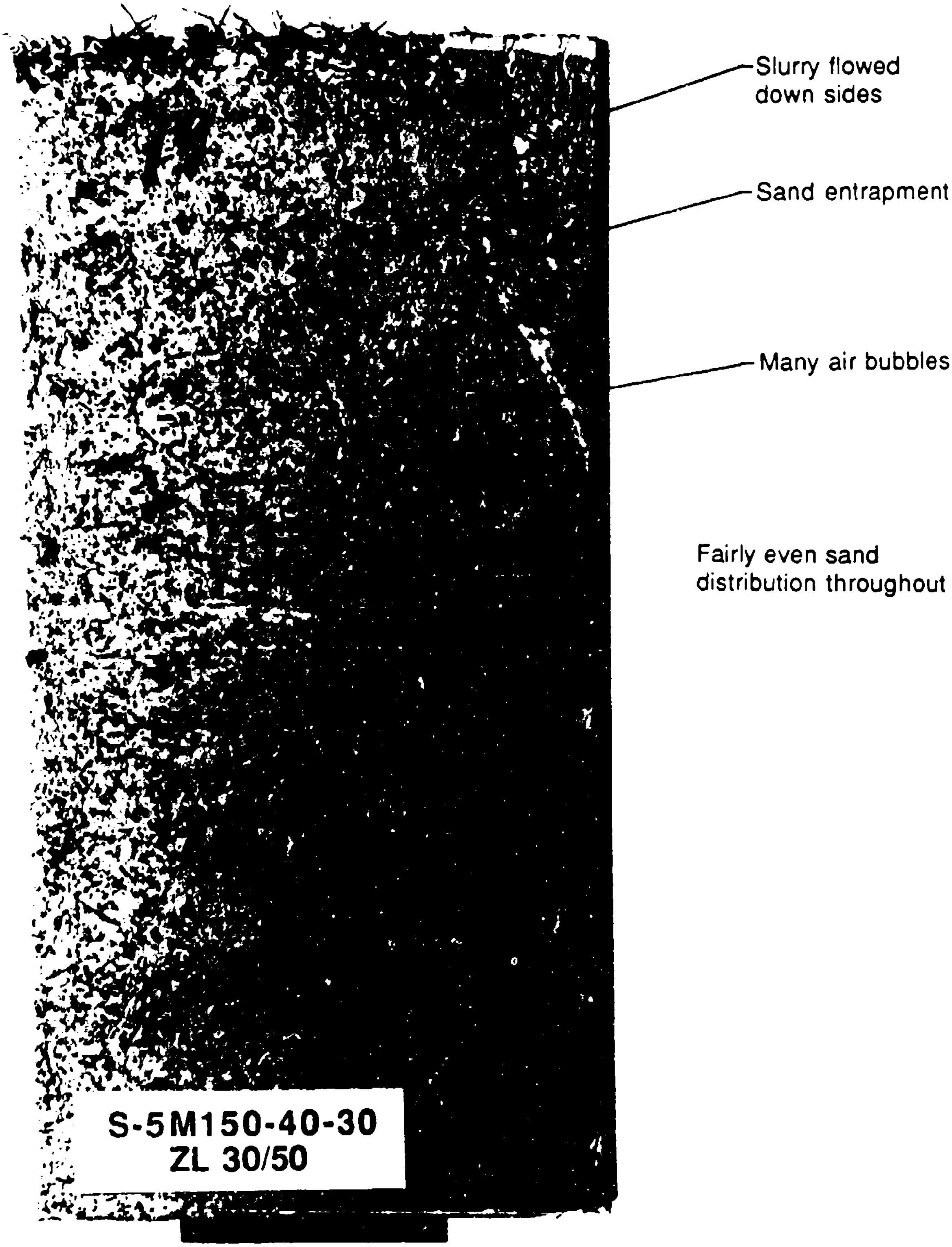


Figure A7. 50-mesh sand (150%) in fluid mix -- ZL 30/50 fibers.

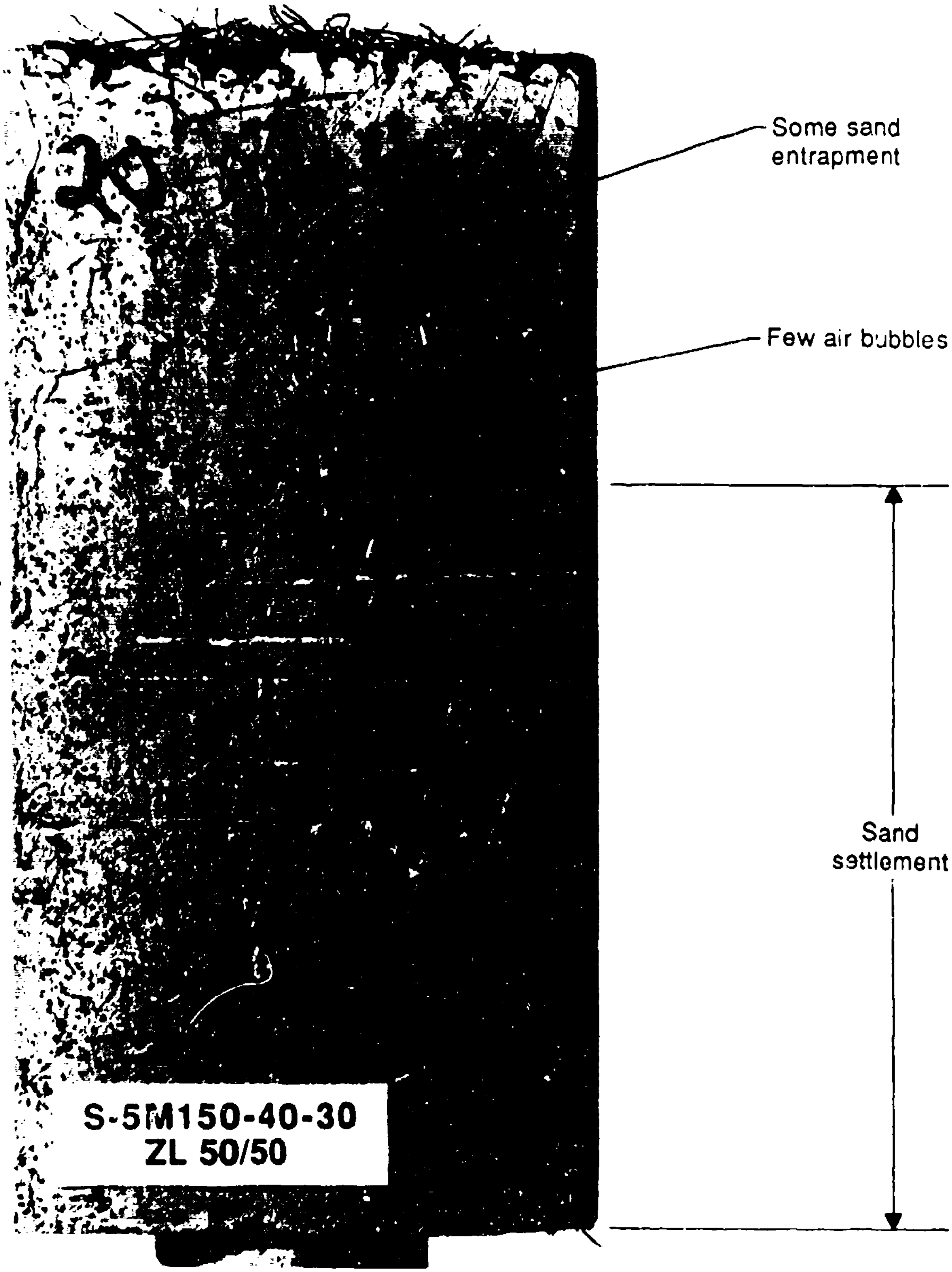


Figure A8. 50-mesh sand (150%) in fluid mix -- ZL 50/50 fibers.

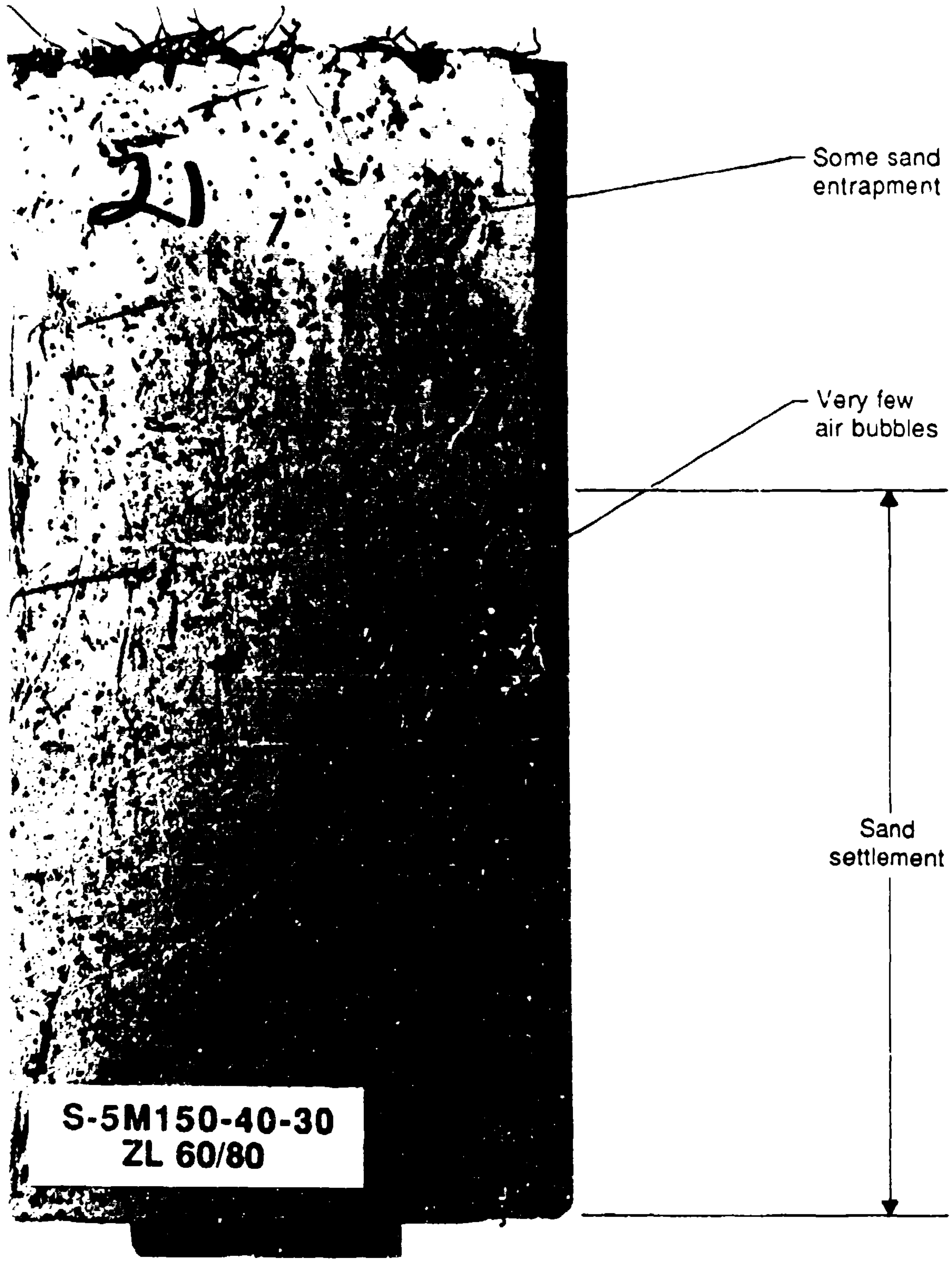


Figure A9. 50-mesh sand (150%) in fluid mix -- ZL 60/80 fibers.

Figure A10. 50-mesh sand (200%) in fluid mix -- ZL 30/50 fibers, much vibration.

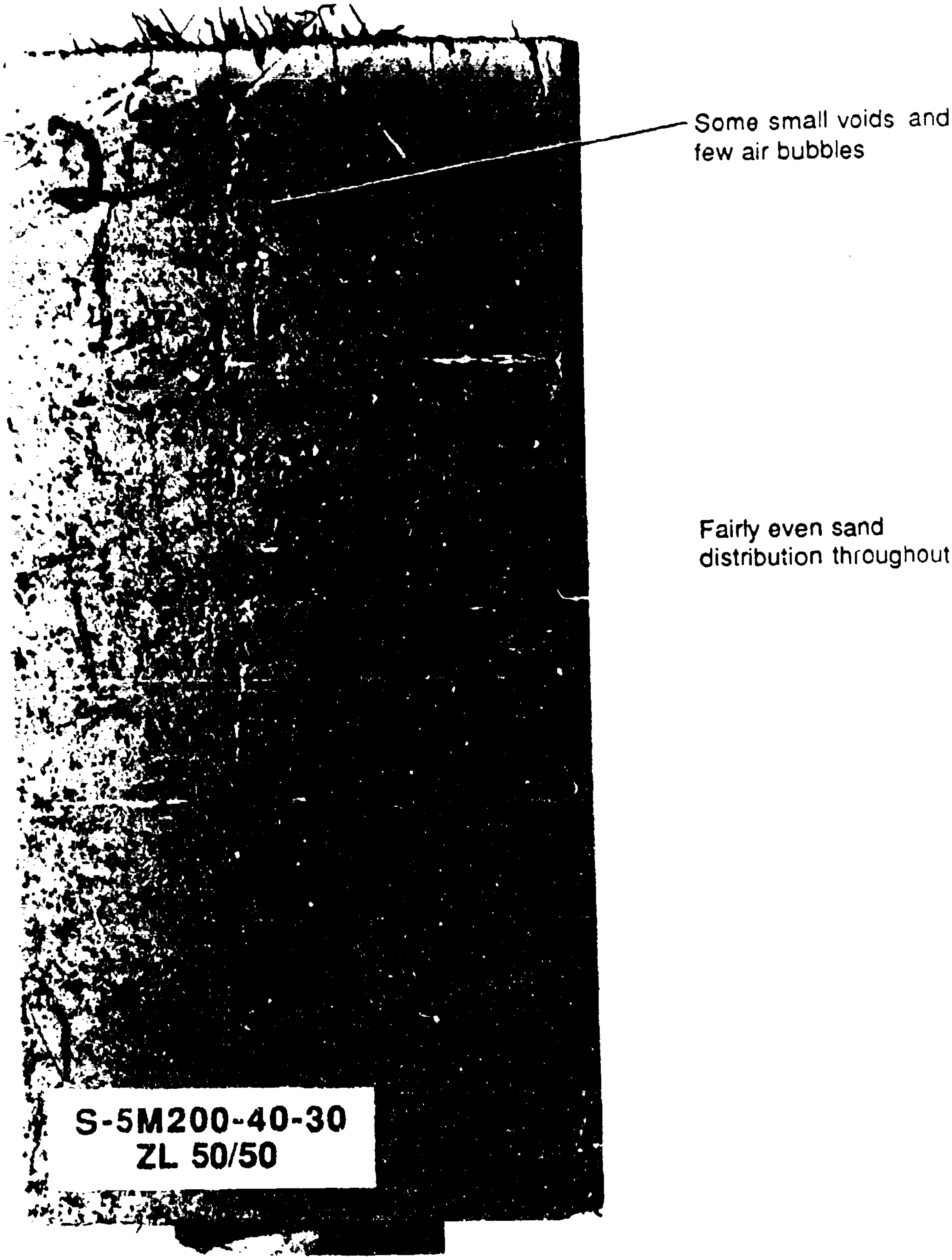


Figure A11. 50-mesh sand (200%) in fluid mix -- ZL 50/50 fibers.

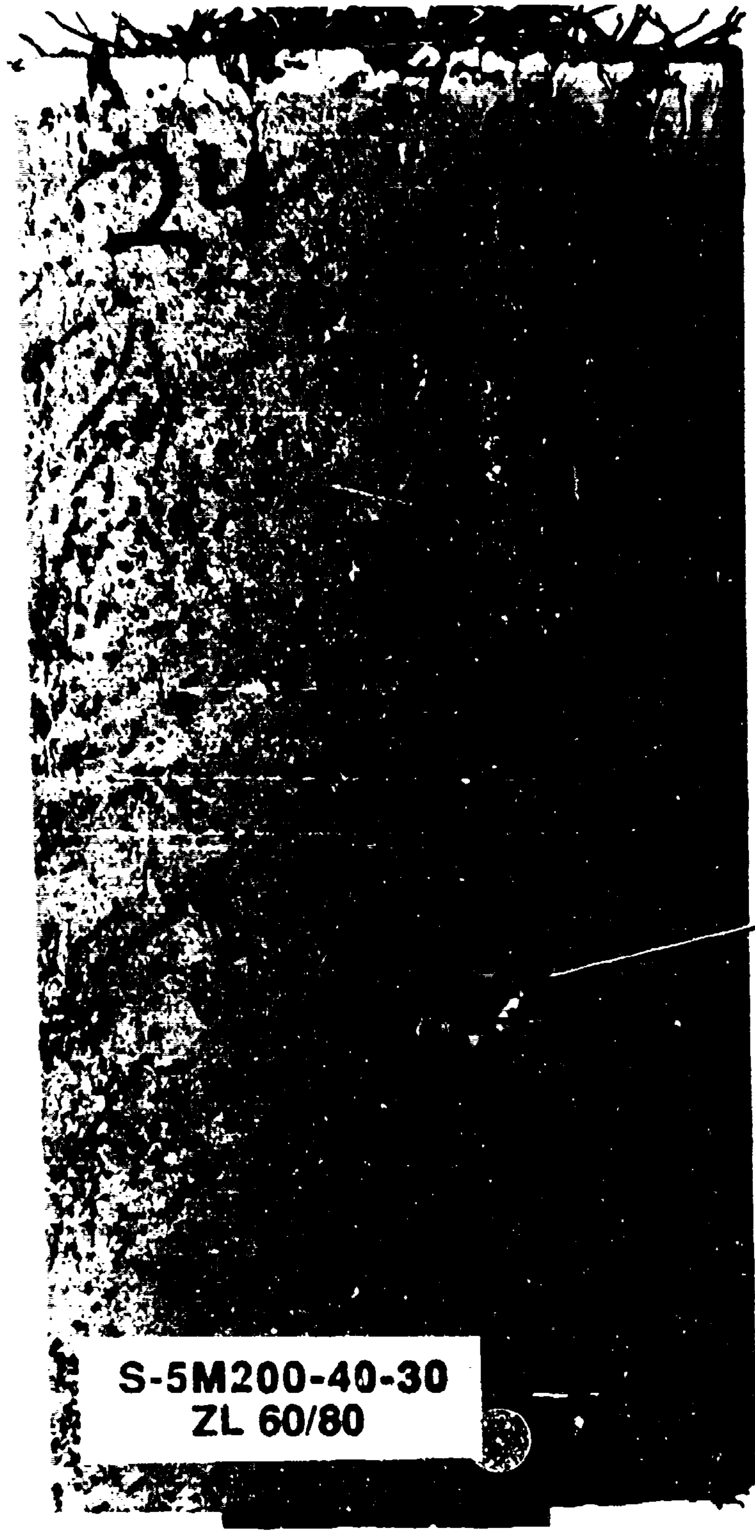


Figure A12. 50-mesh sand (200%) in fluid mix -- ZL 60/80 fibers.

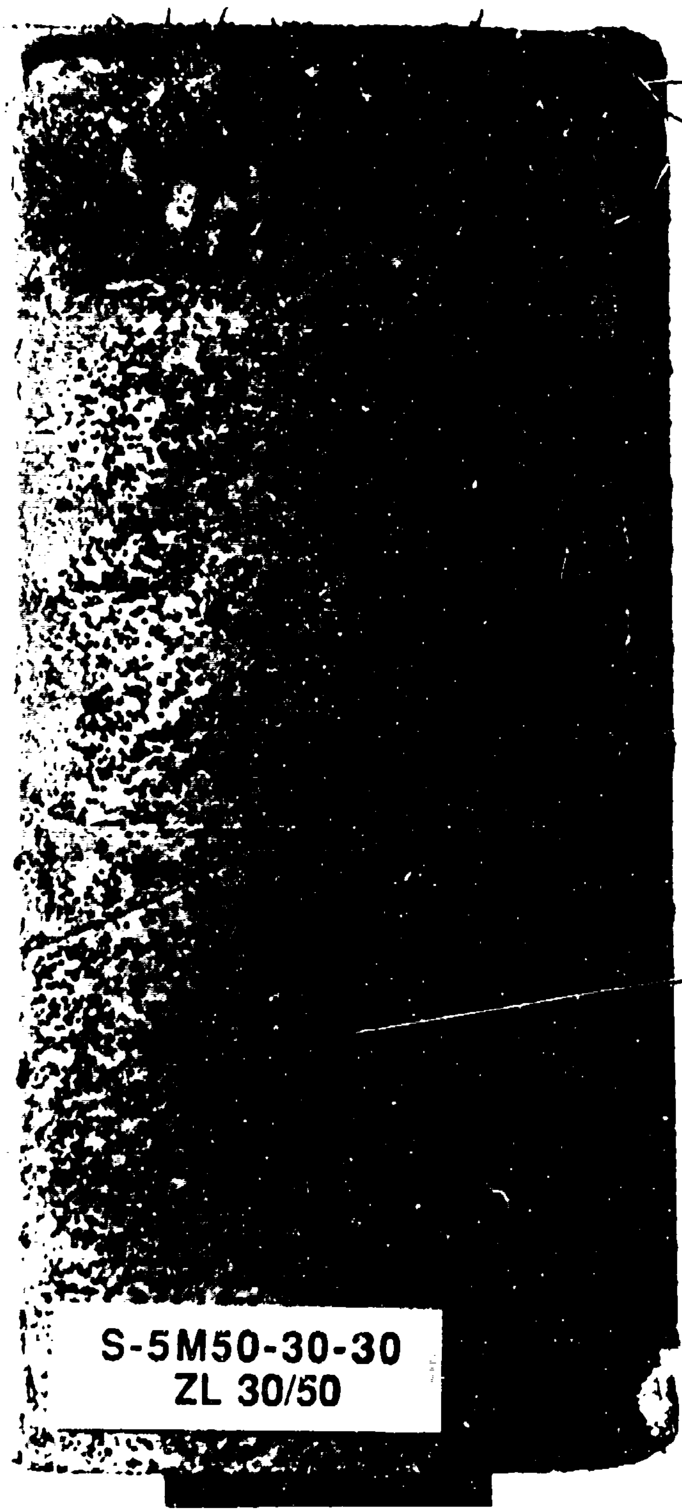


Figure A13. 50-mesh sand (50%) in viscous mix -- ZL 30/50 fibers, much vibration.

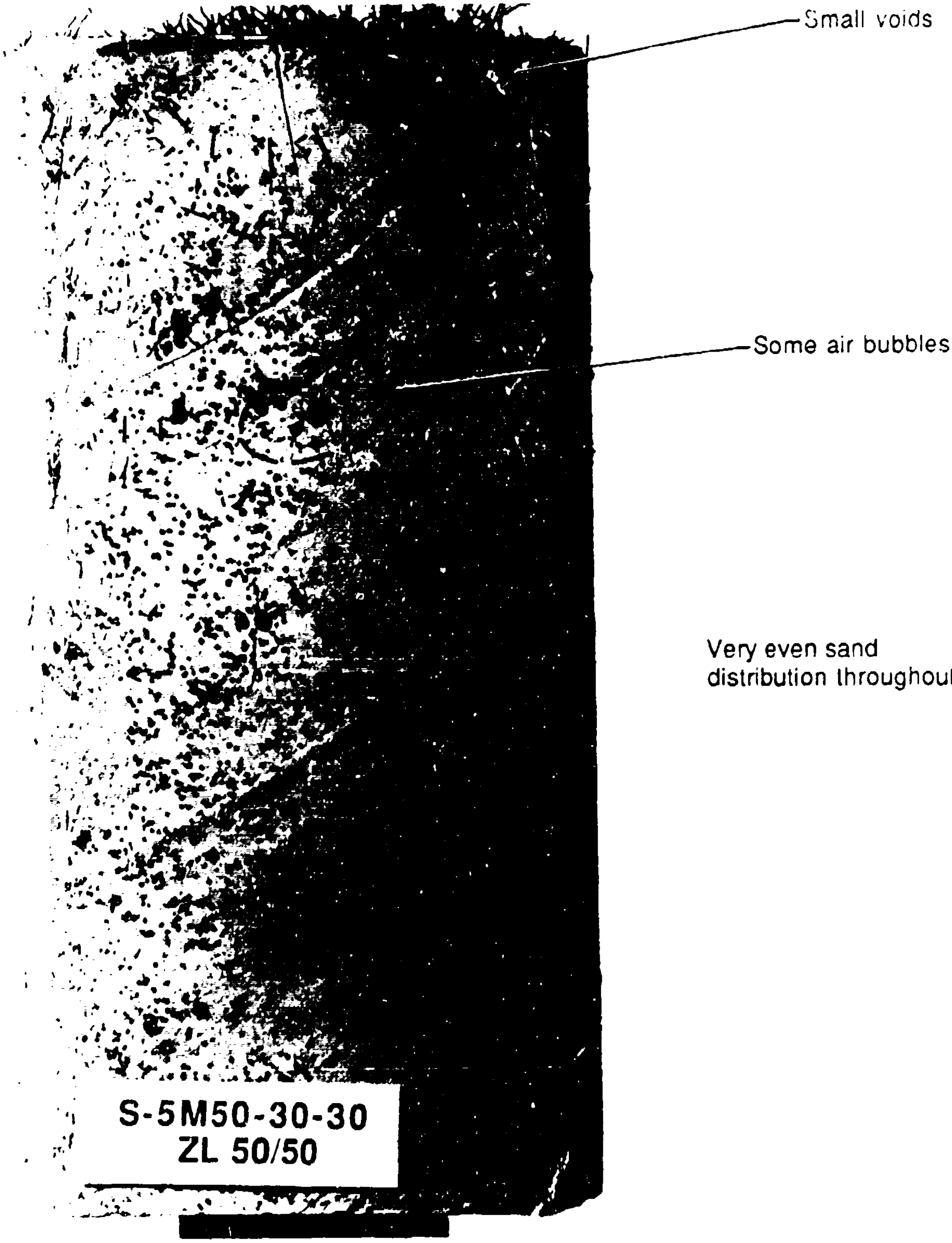


Figure A14. 50-mesh sand (50%) in viscous mix -- ZL 50/50 fibers.

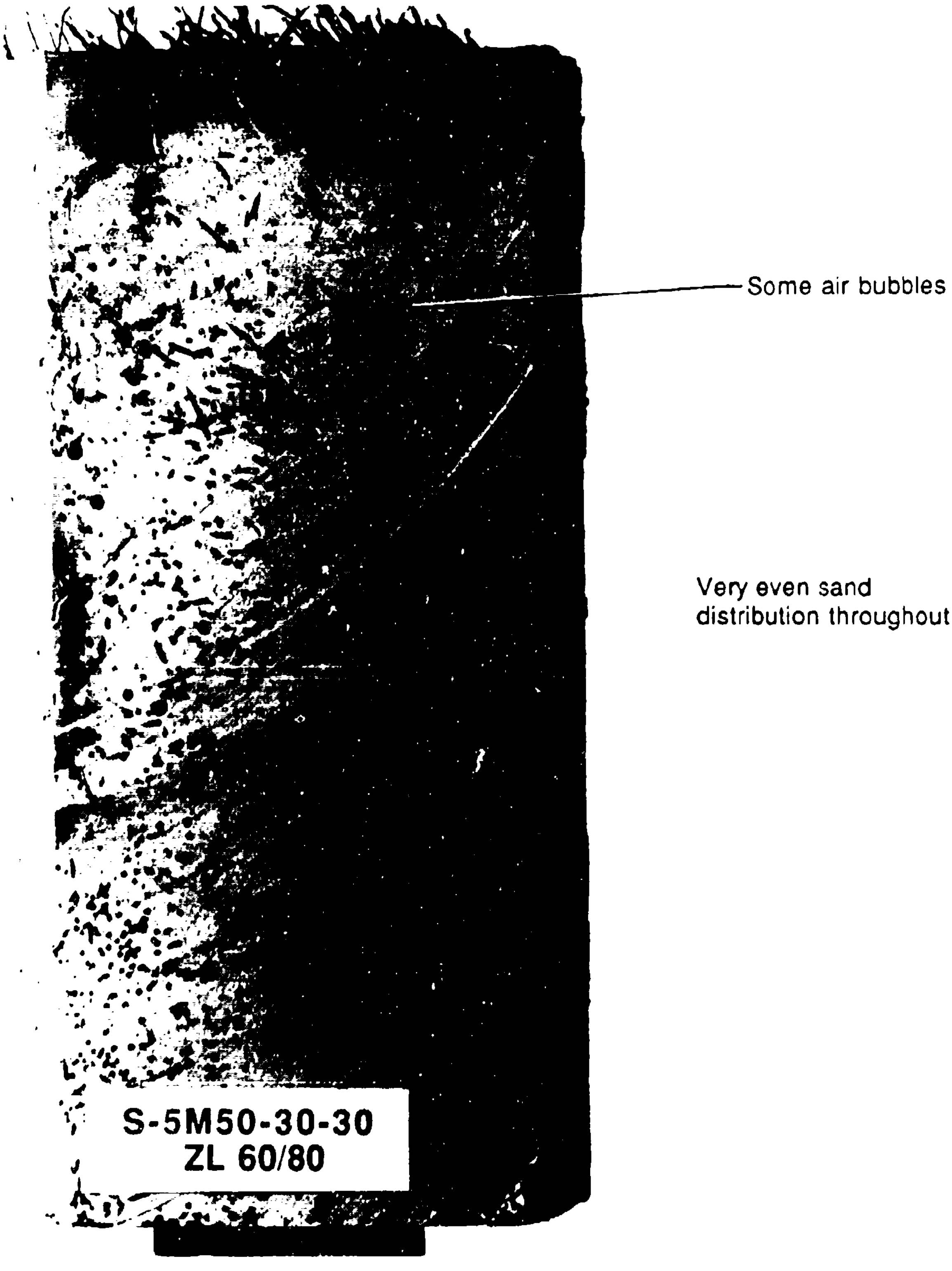


Figure A15. 50-mesh sand (50%) in viscous mix -- ZL 60/80 fibers.

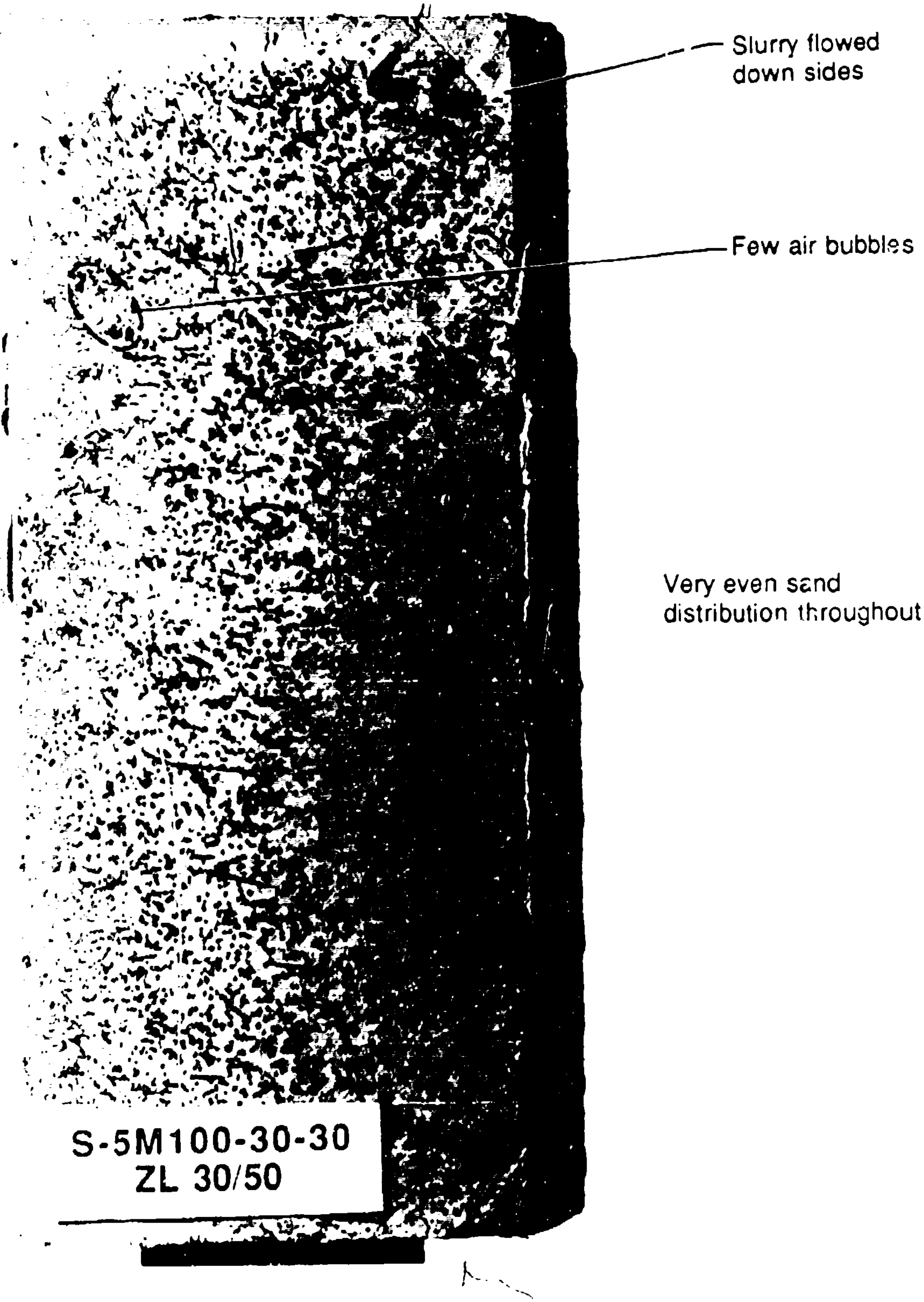
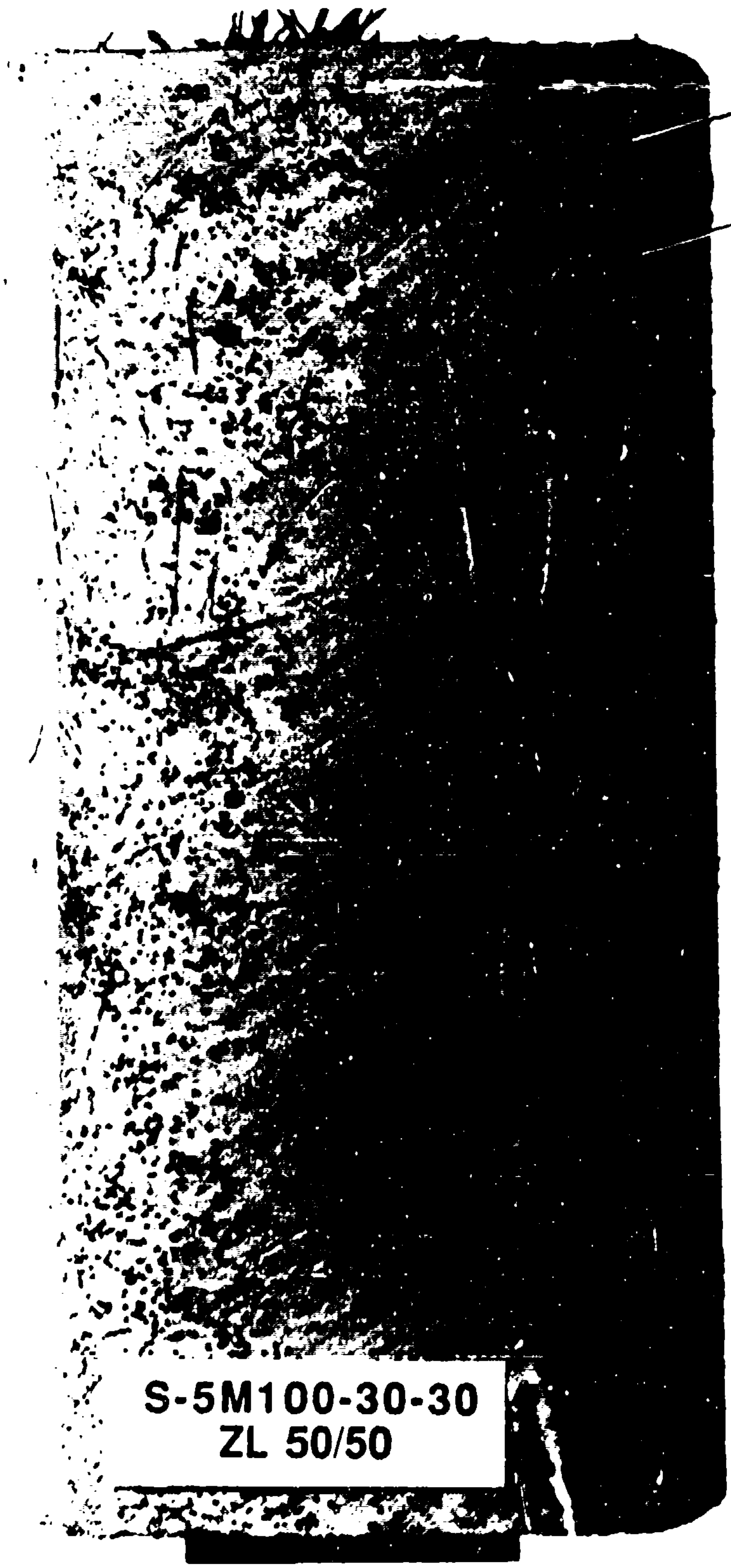


Figure A16. 50-mesh sand (100%) in viscous mix -- ZL 30/50 fibers, much vibration.



Slurry flowed down sides slightly

Some air bubbles

Very even sand distribution throughout

Figure A17. 50-mesh sand (100%) in viscous mix -- ZL 50/50 fibers, moderate vibration.

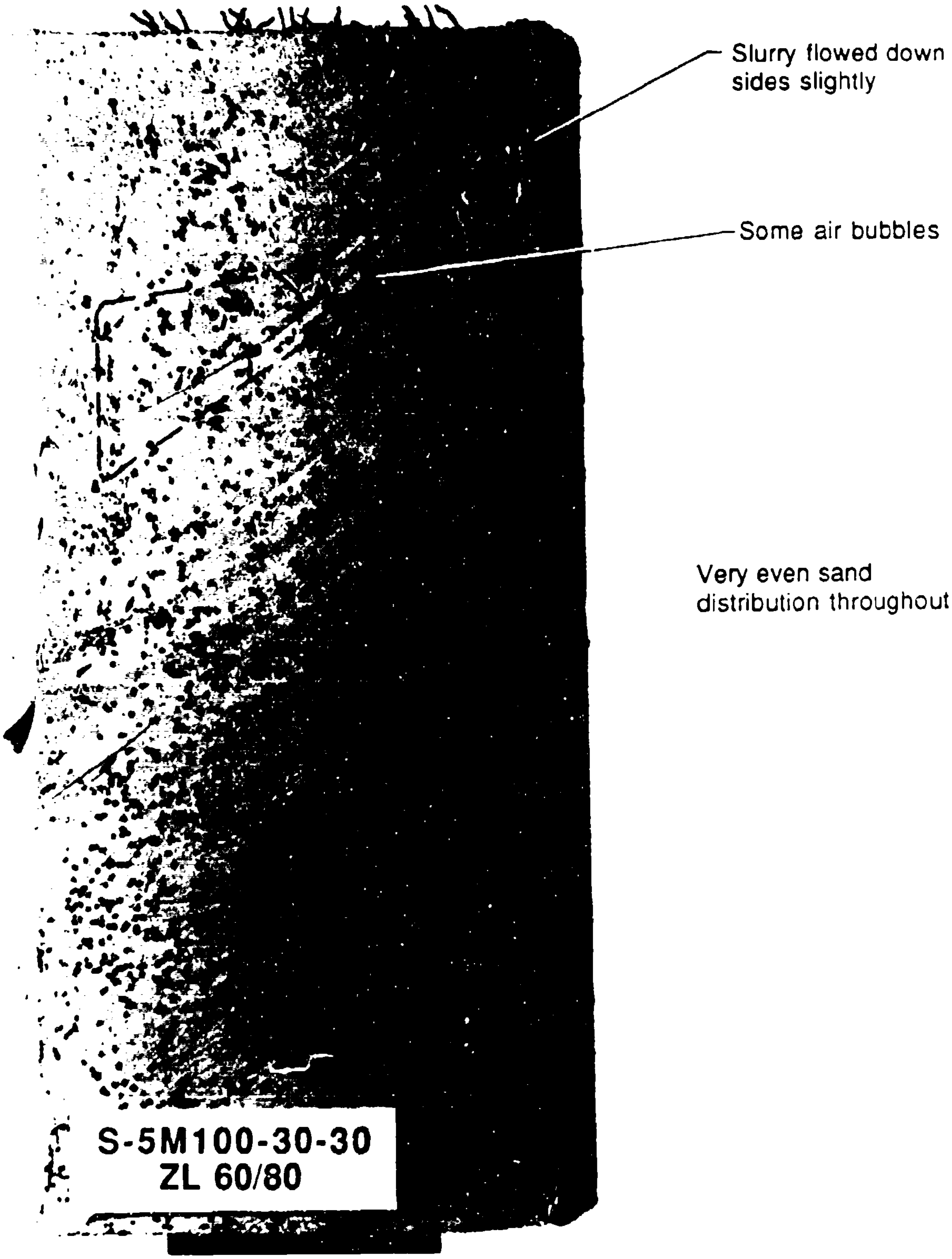


Figure A18. 50-mesh sand (100%) in viscous mix -- ZL 60/80 fibers, moderate vibration.

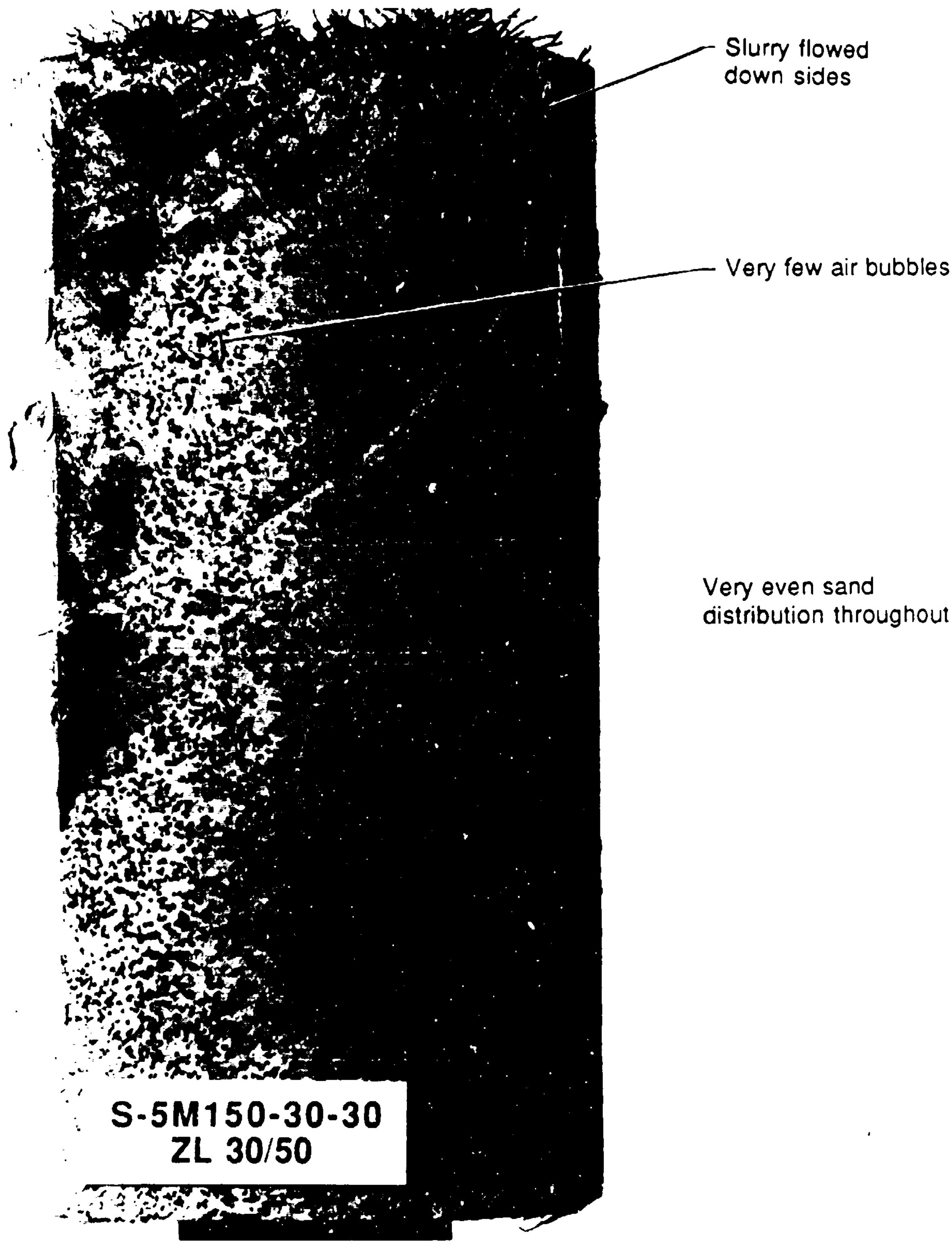


Figure A19. 50-mesh sand (150%) in viscous mix -- ZL 30/50 fibers, much vibration.

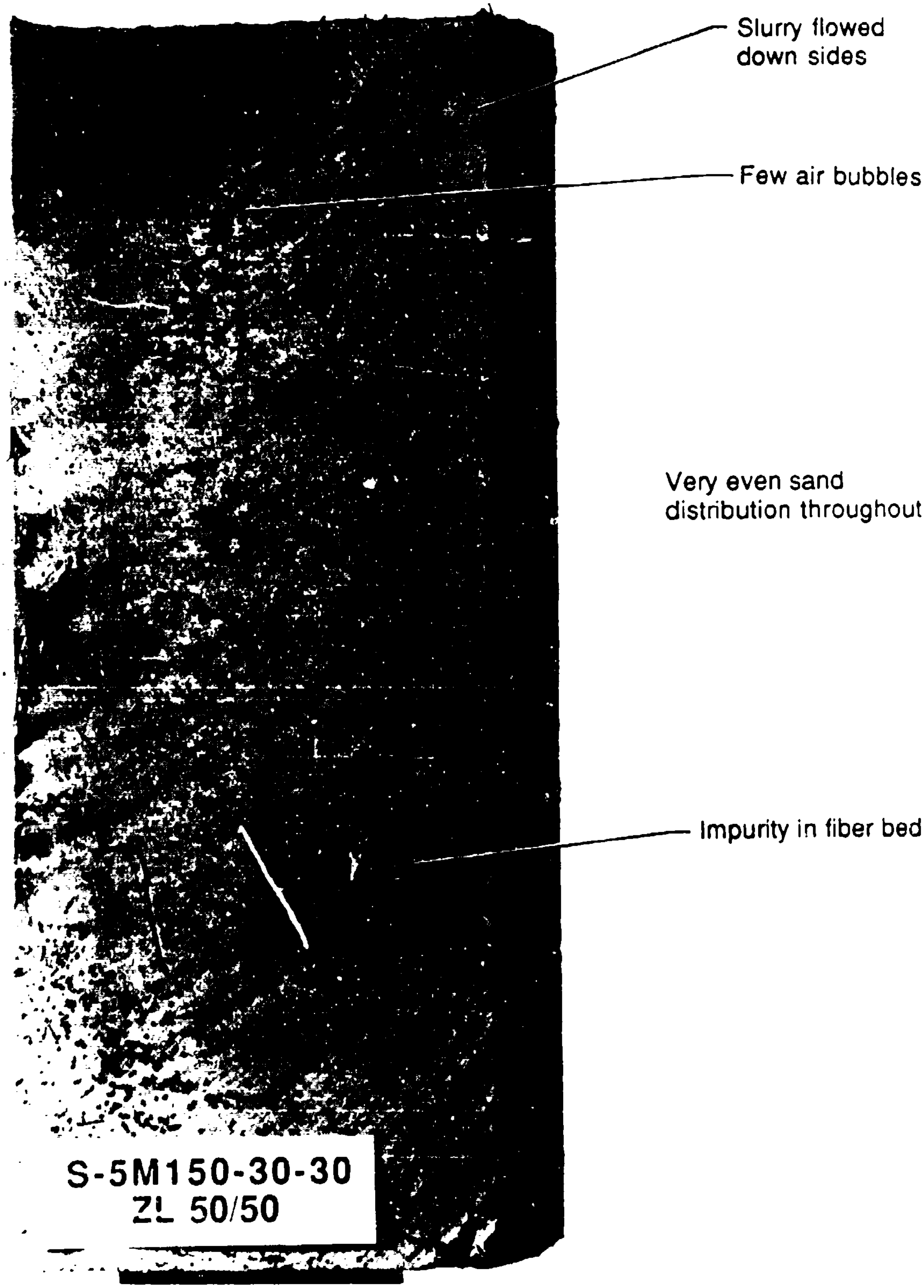


Figure A20. 50-mesh sand (150%) in viscous mix -- ZL 50/50 fibers, moderate vibration.

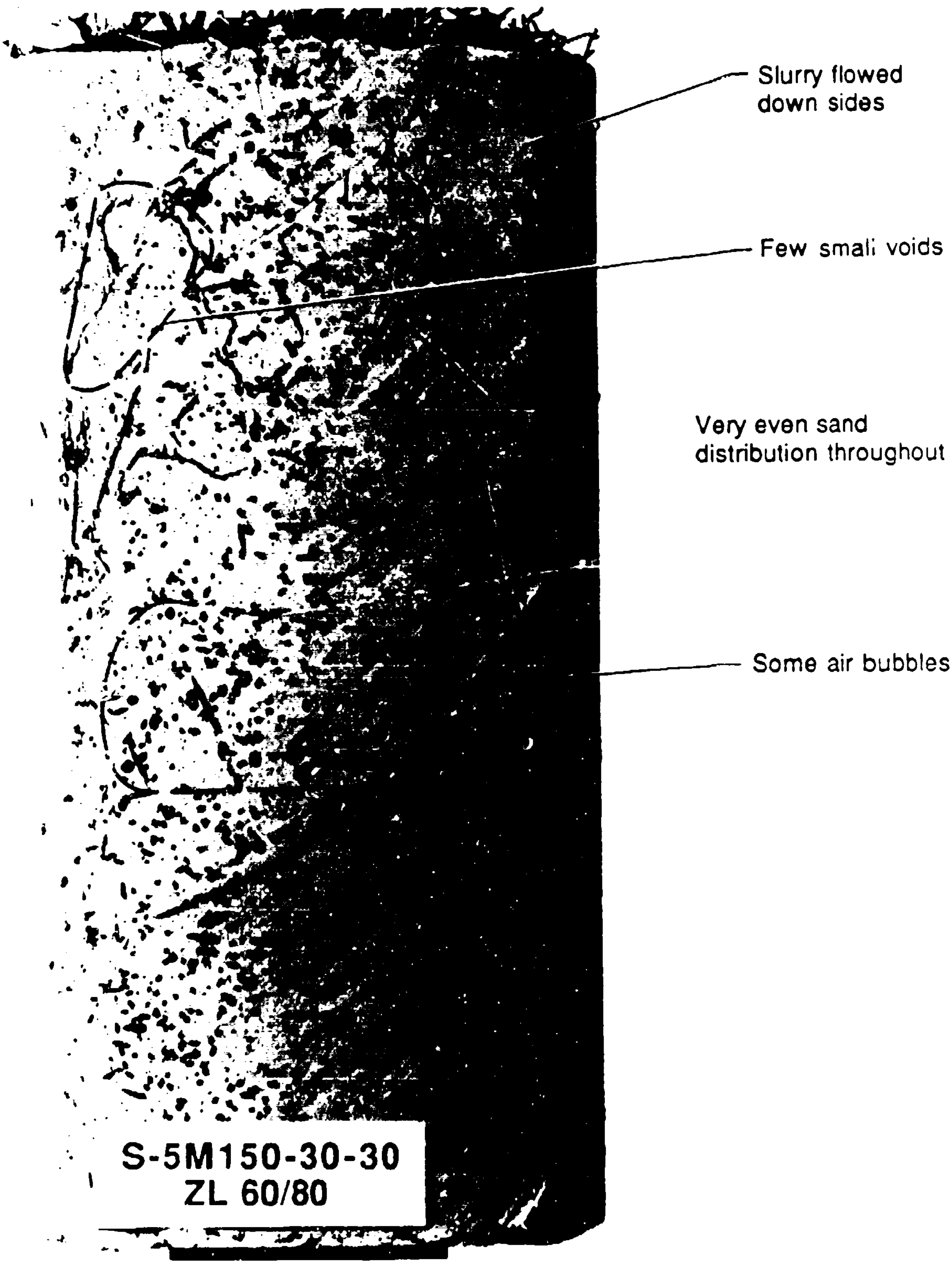


Figure A21. 50-mesh sand (150%) in viscous mix -- ZL 60/80 fibers, moderate vibration.

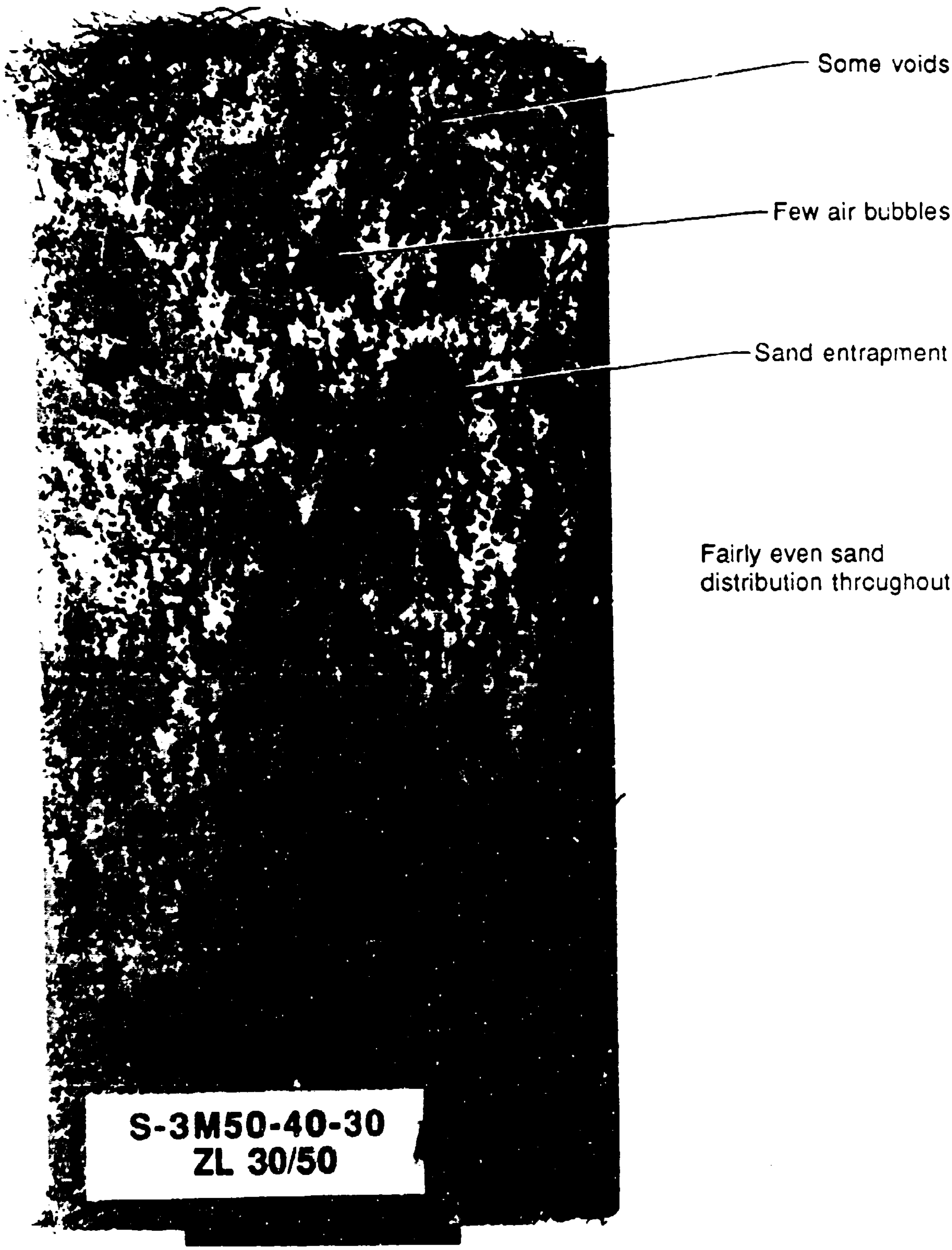


Figure A22. 30-mesh sand (50%) in fluid mix -- ZL 30/50 fibers.

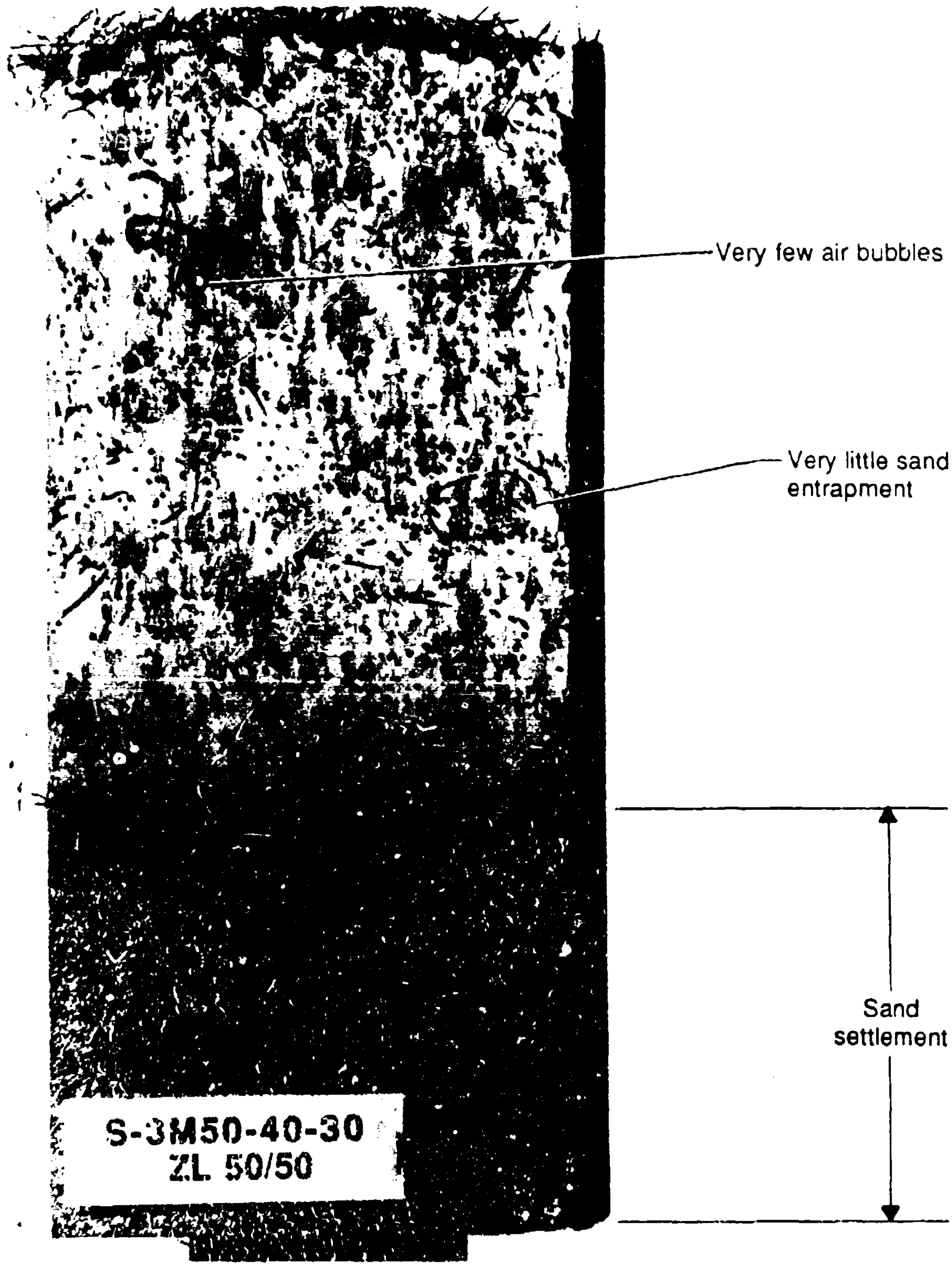


Figure A23. 30-mesh sand (50%) in fluid mix -- ZL 50/50 fibers.

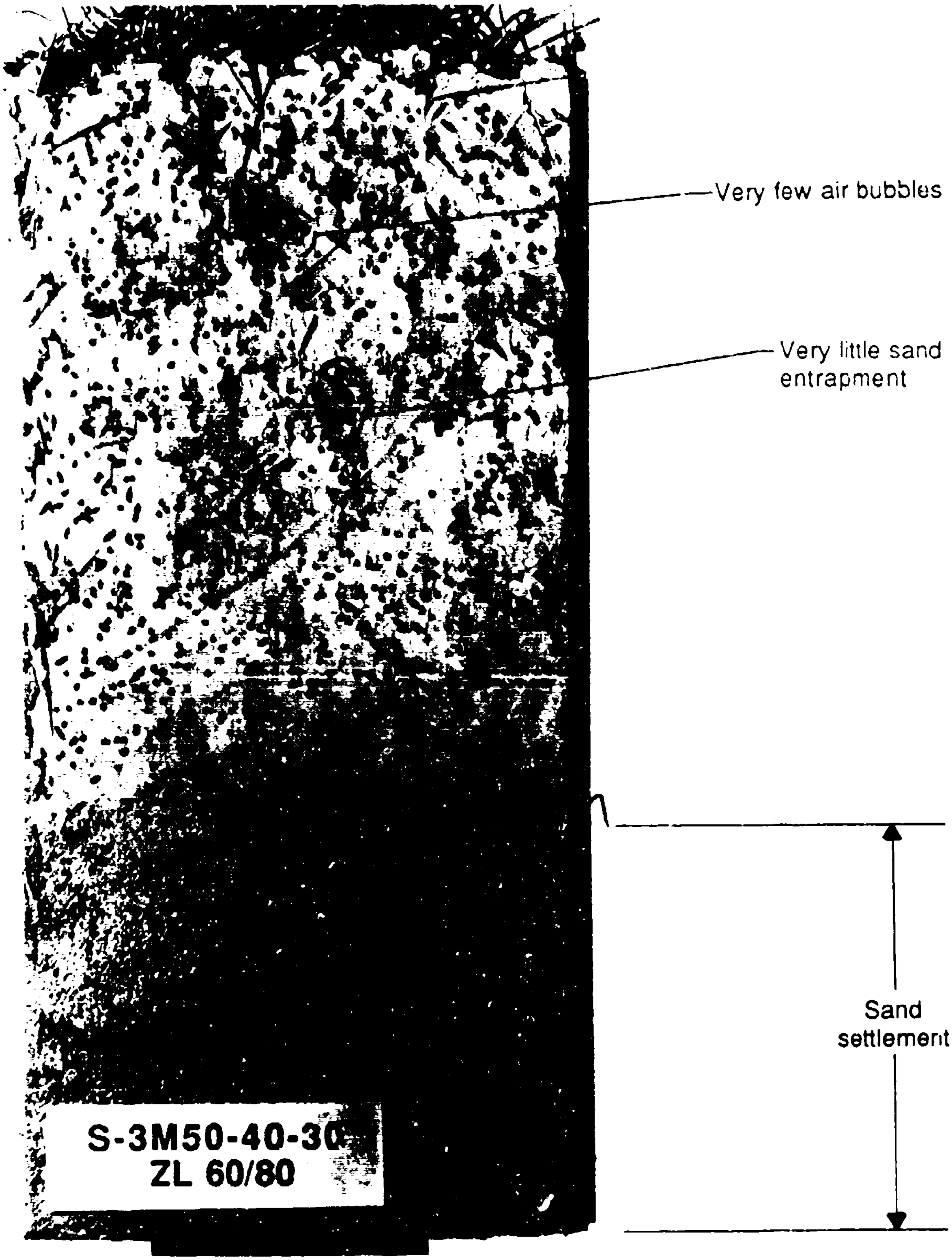


Figure A24. 30-mesh sand (50%) in fluid mix -- ZL 60/80 fibers.

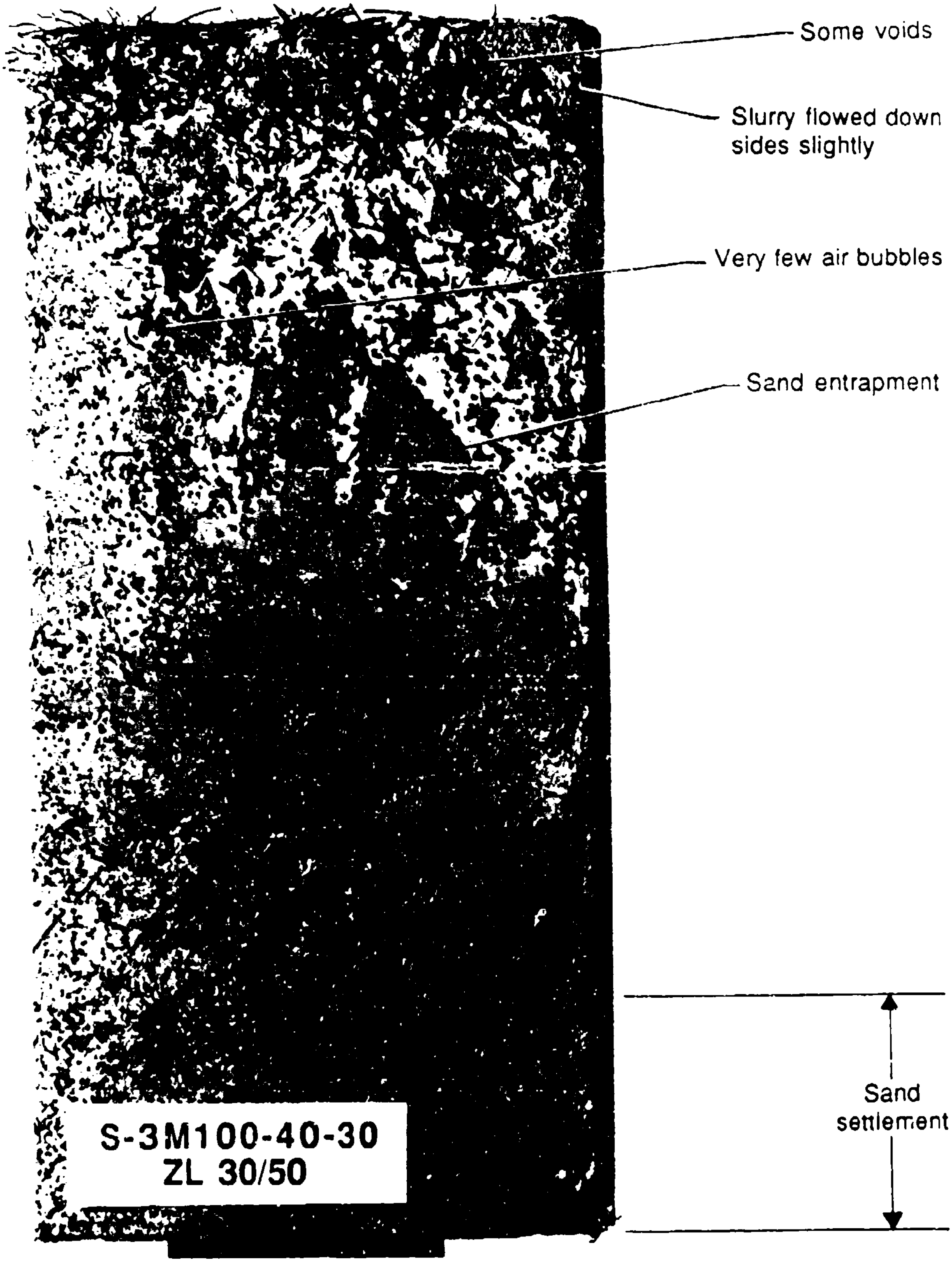


Figure A25. 30-mesh sand (100%) in fluid mix -- ZL 30/50 fibers.

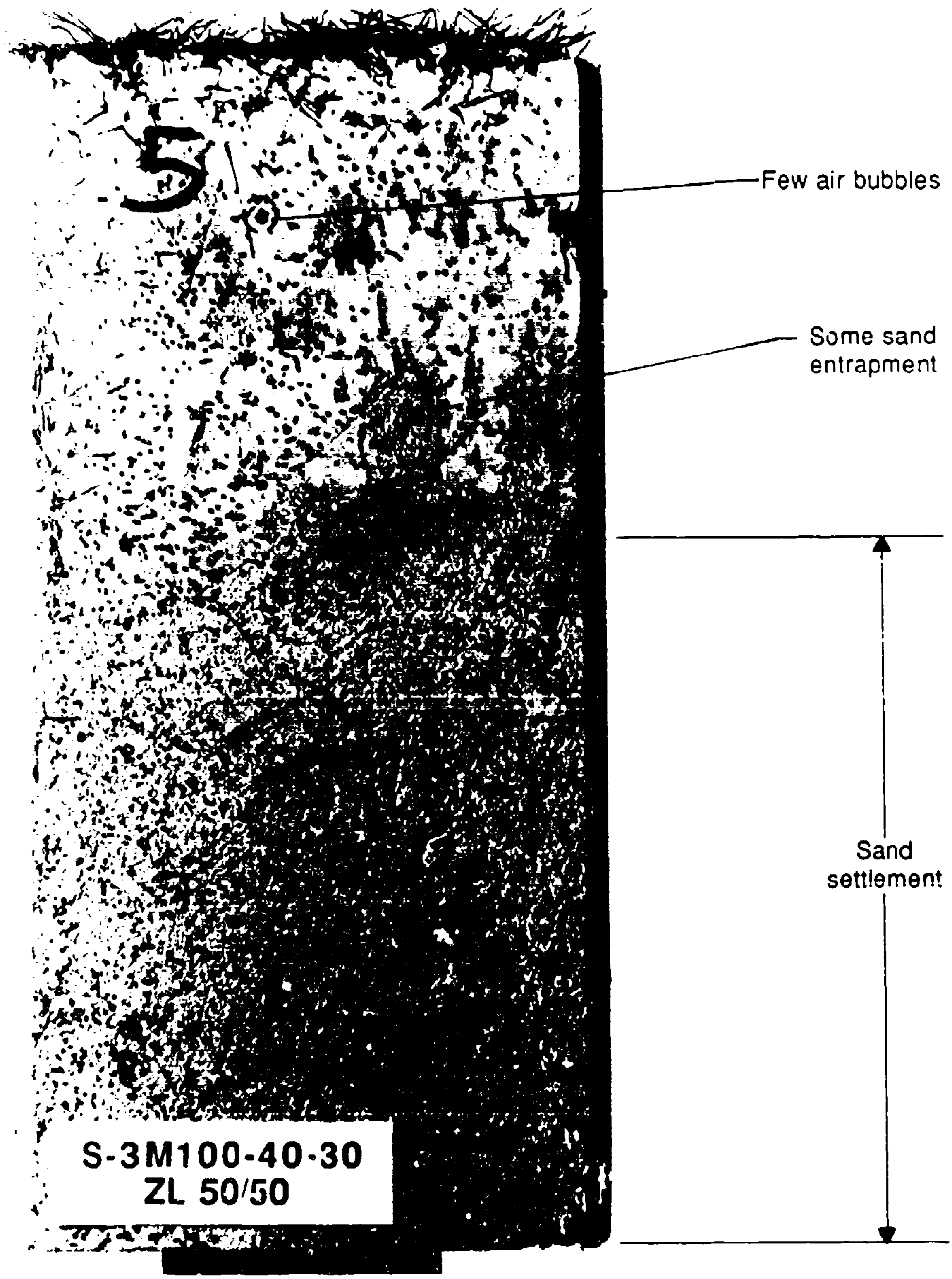


Figure A26. 30-mesh sand (100%) in fluid mix -- ZL 50/50 fibers.

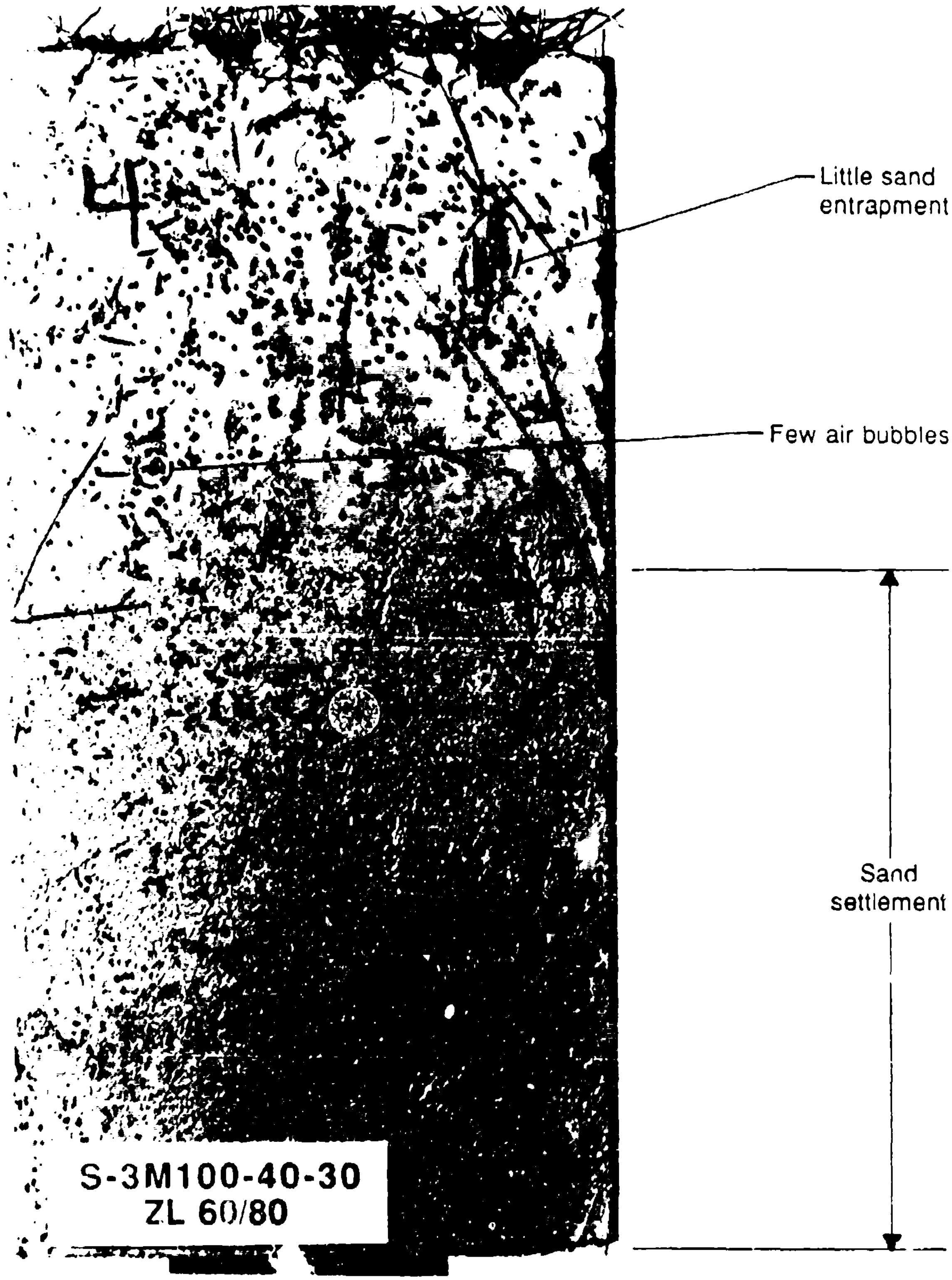


Figure A27. 30-mesh sand (100%) in fluid mix -- ZL 60/80 fibers.

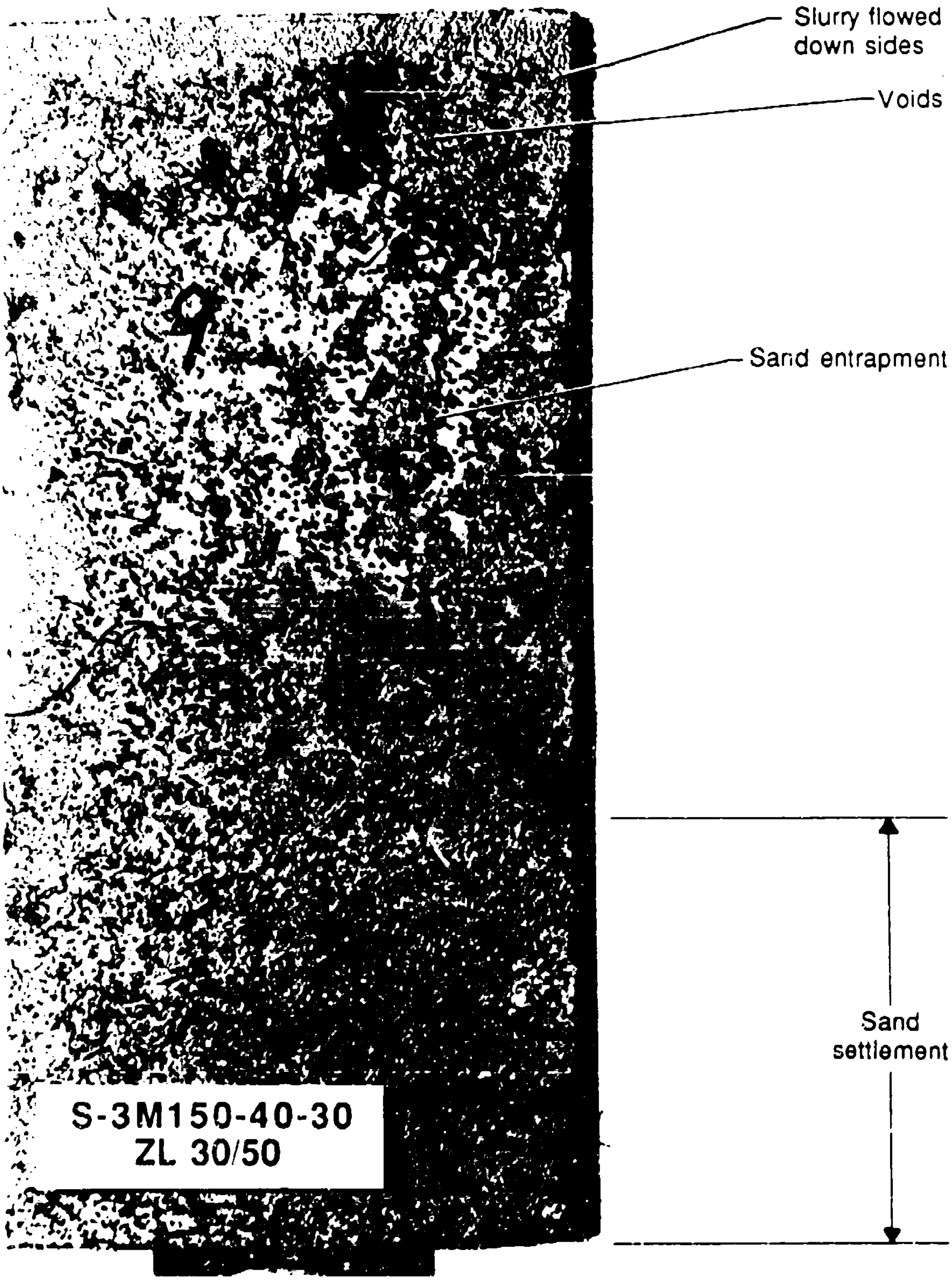


Figure A28. 30-mesh sand (150%) in fluid mix -- ZL 30/50 fibers, much vibration.

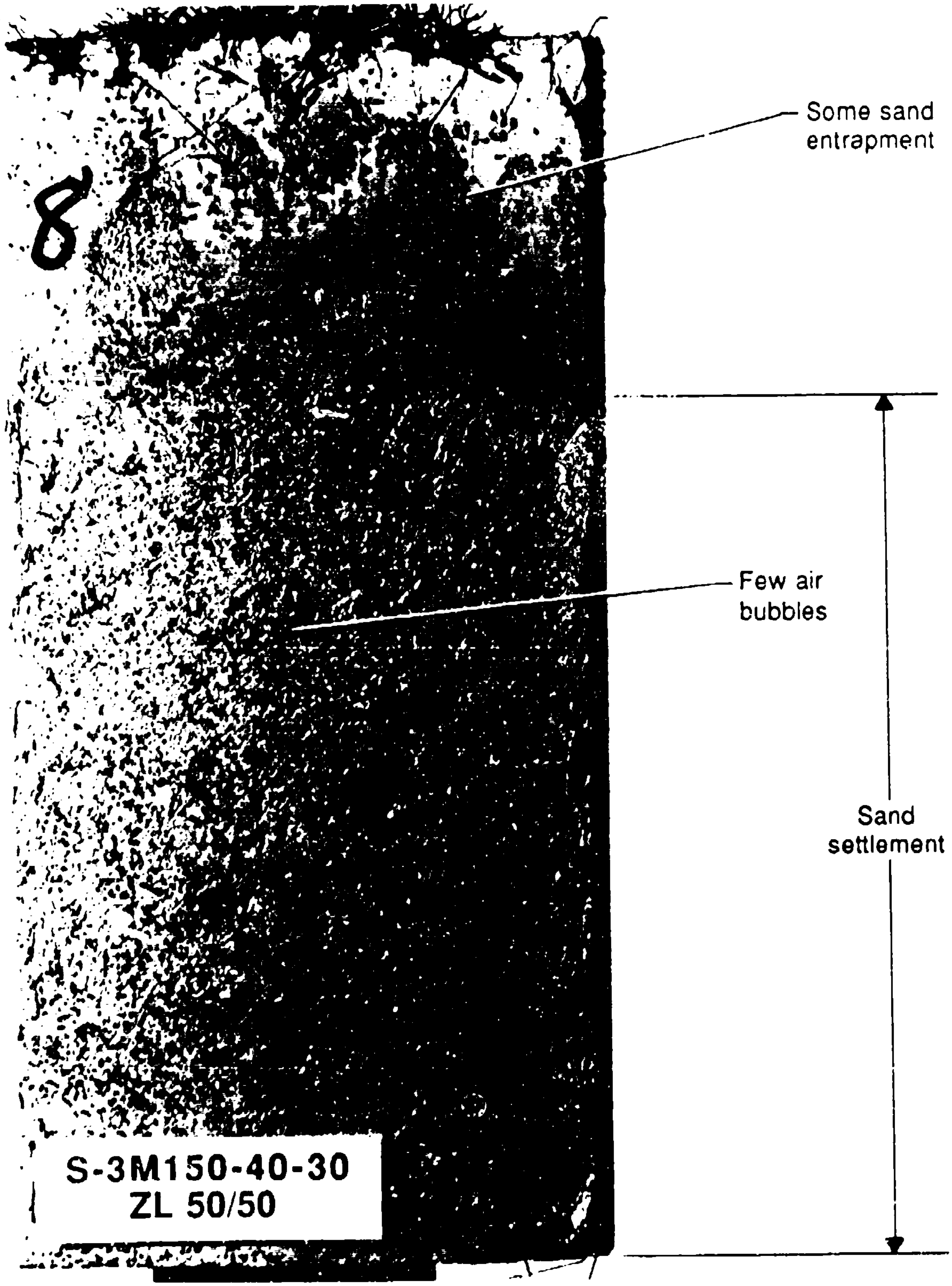


Figure A29. 30-mesh sand (150%) in fluid mix -- ZL 50/50 fibers.

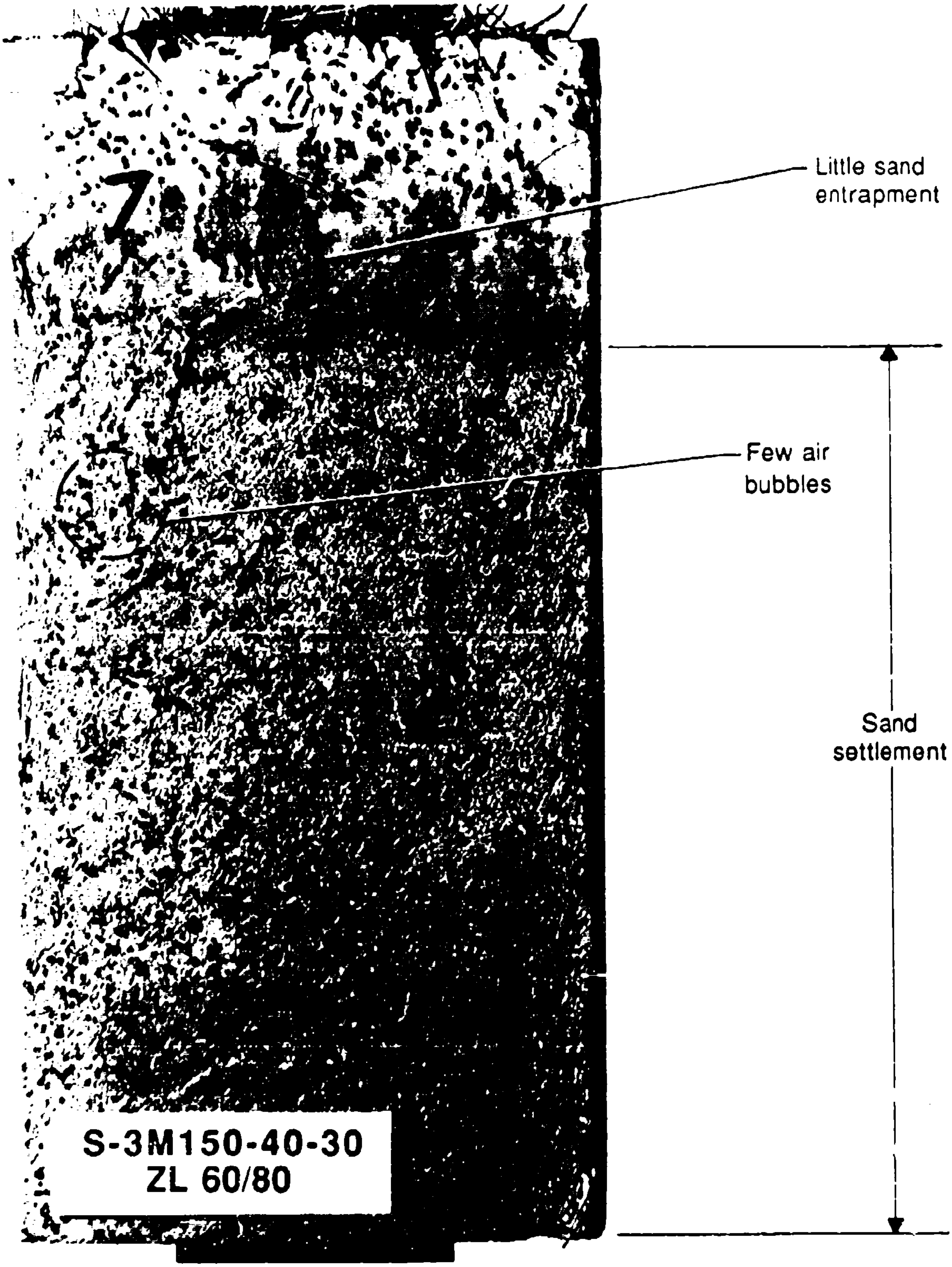


Figure A30. 30-mesh sand (150%) in fluid mix -- ZL 60/80 fibers.

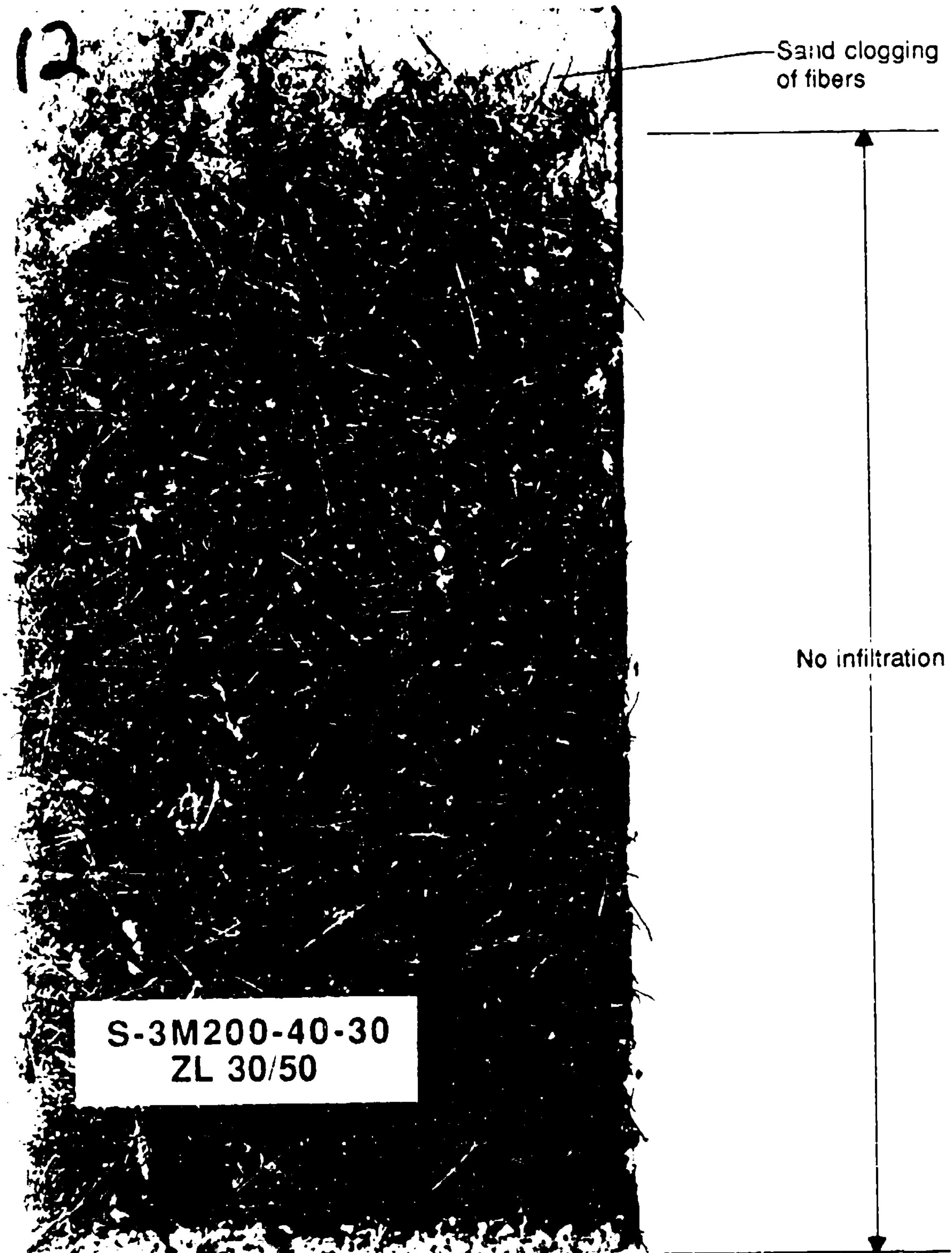


Figure A31. 30-mesh sand (200%) in fluid mix -- ZL 30/50 fibers, much vibration.

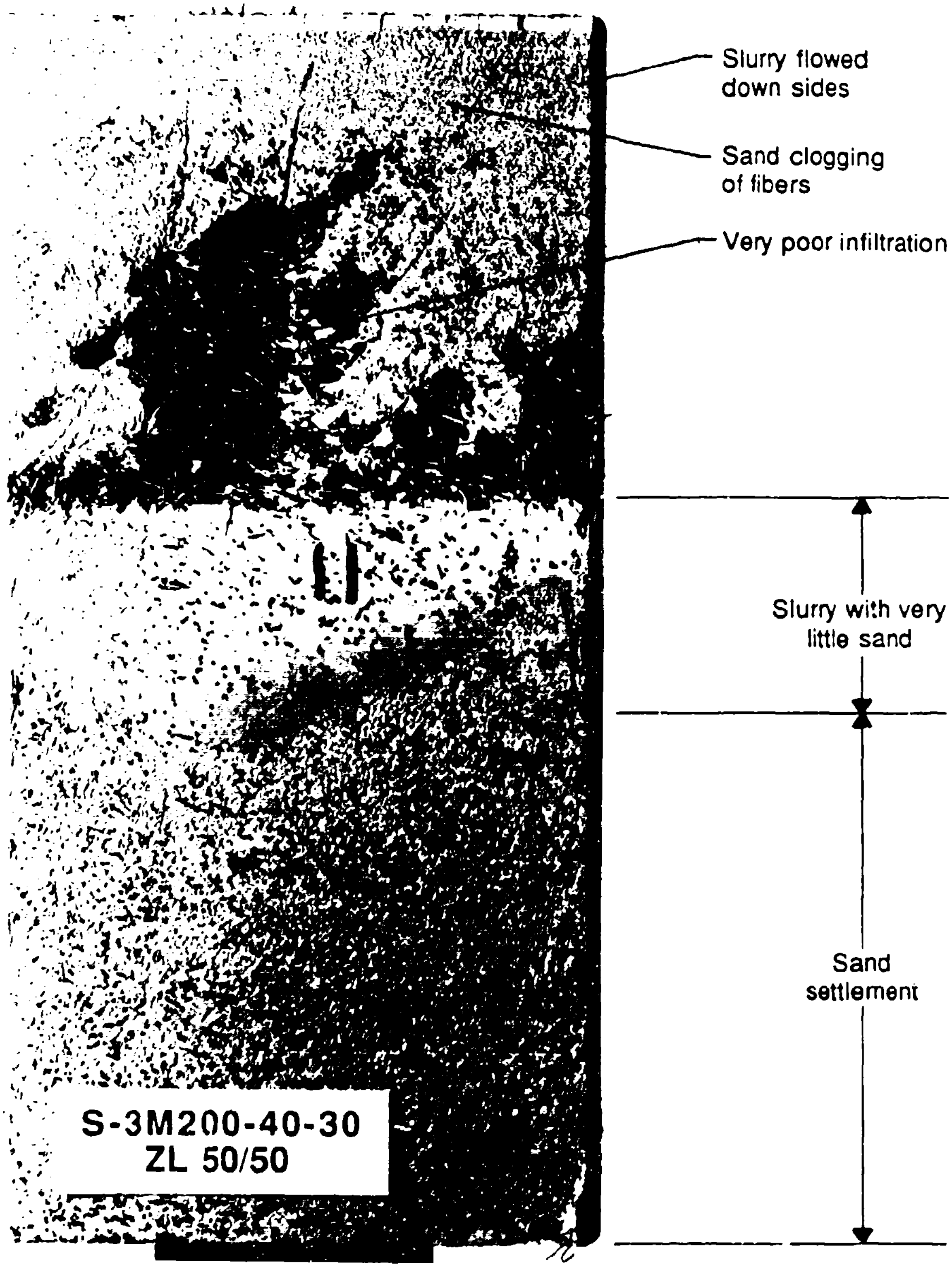


Figure A32. 30-mesh sand (200%) in fluid mix -- ZL 50/50 fibers, moderate vibration.

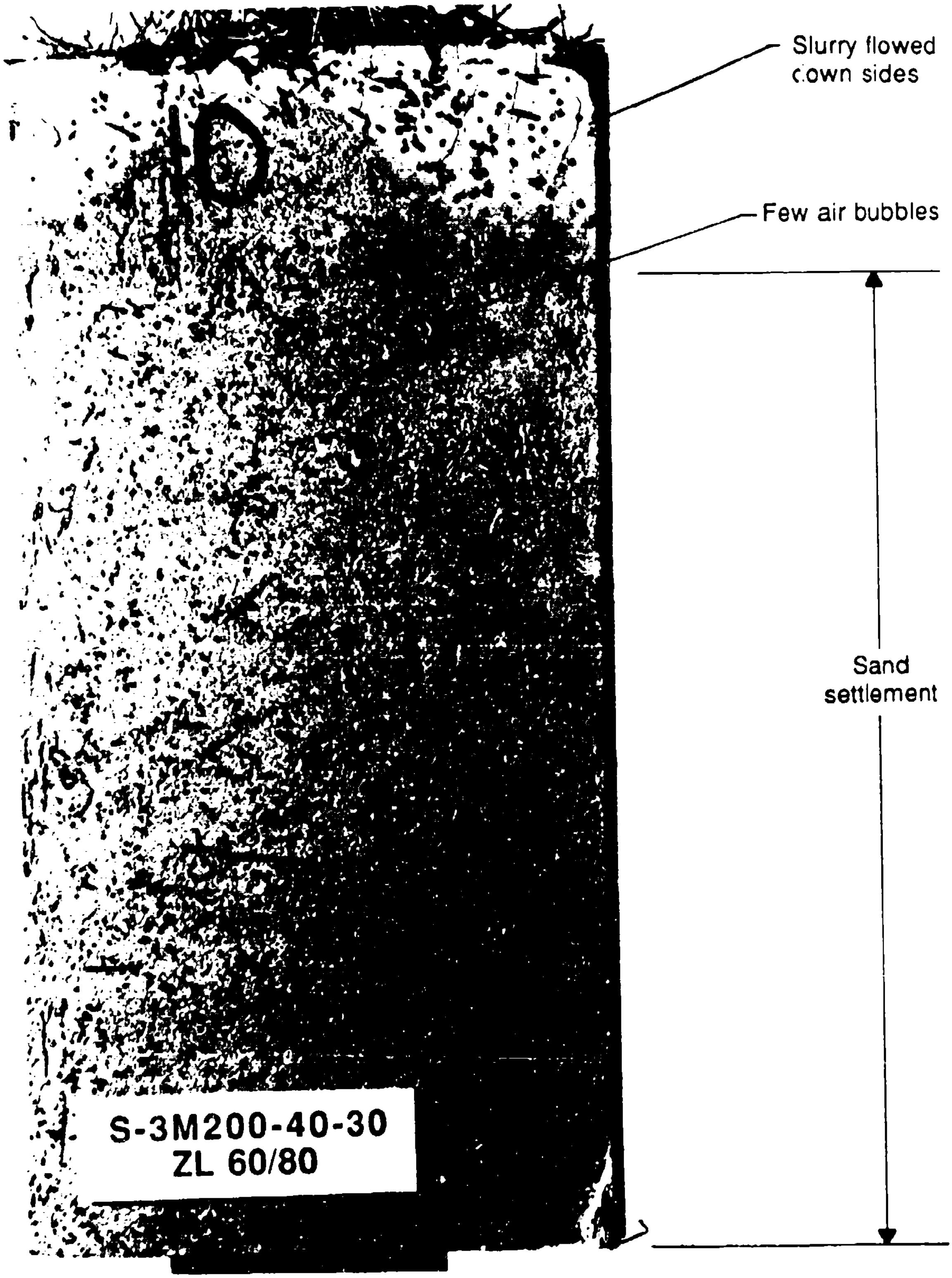


Figure A33. 30-mesh sand (200%) in fluid mix -- ZL 60/80 fibers, moderate vibration.

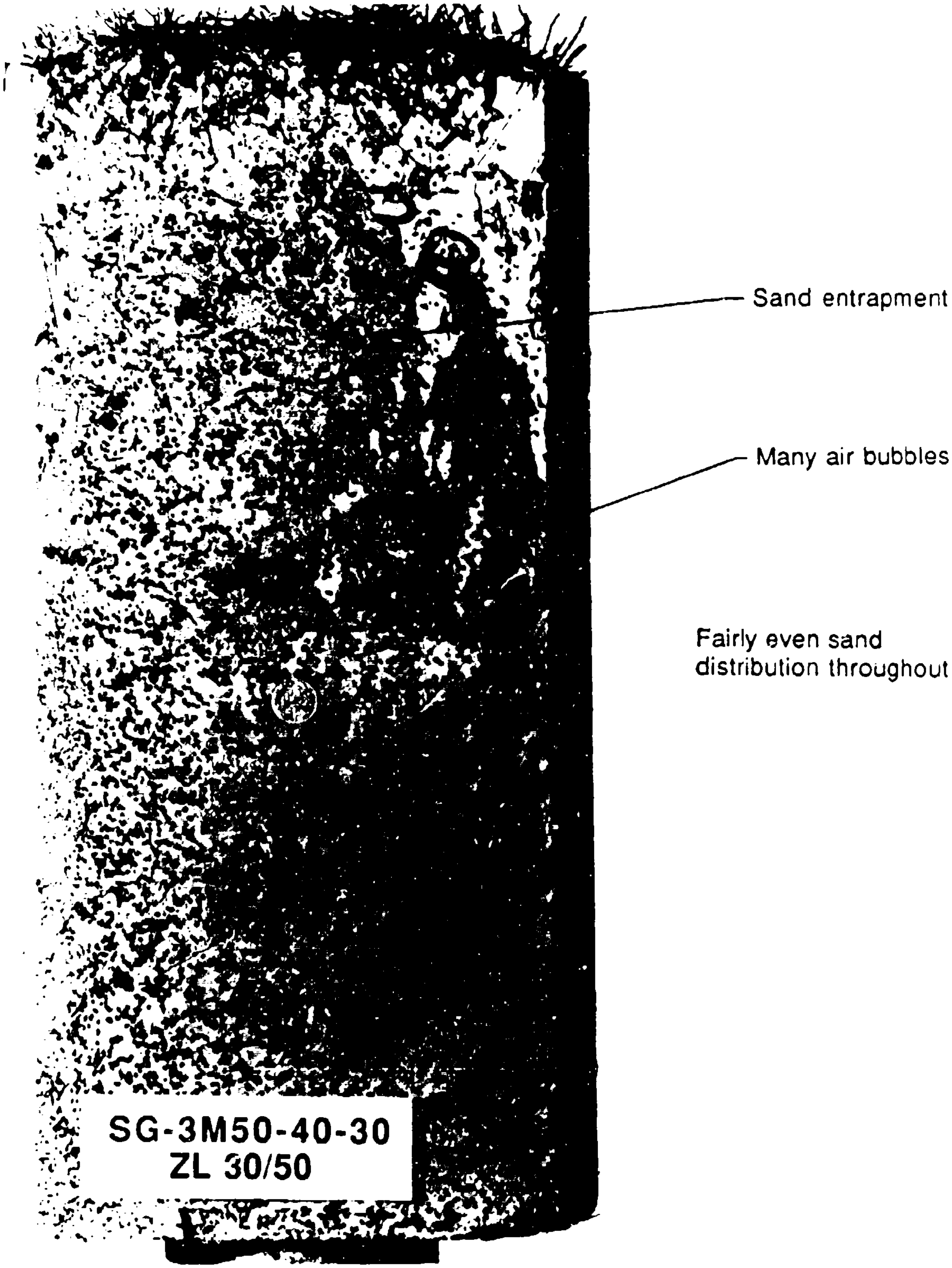


Figure A34. 30-mesh sand (50%) in fluid mix -- ZL 30/50 fibers, viscosifier.

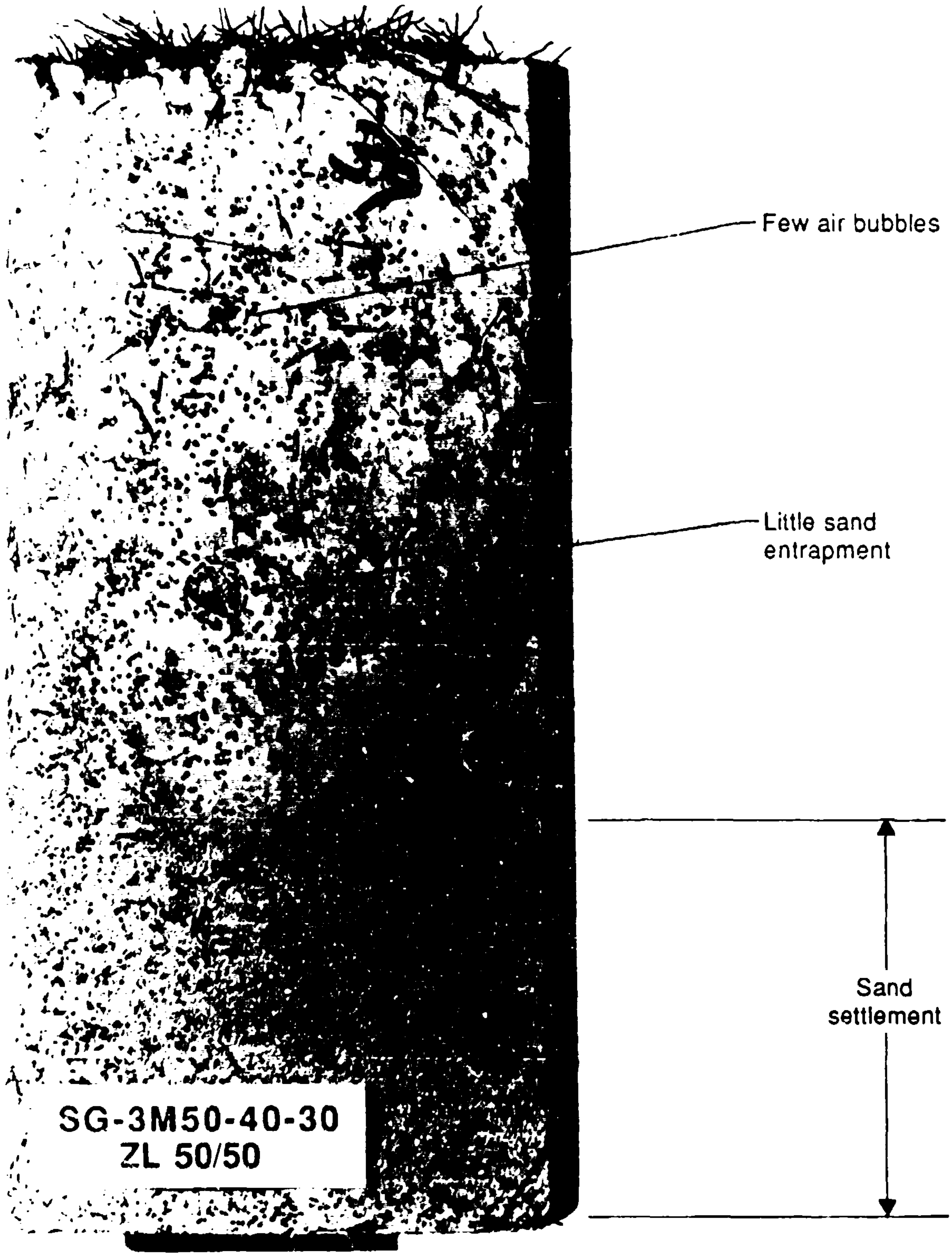


Figure A35. 30-mesh sand (50%) in fluid mix -- ZL 50/50 fibers, viscosifier.

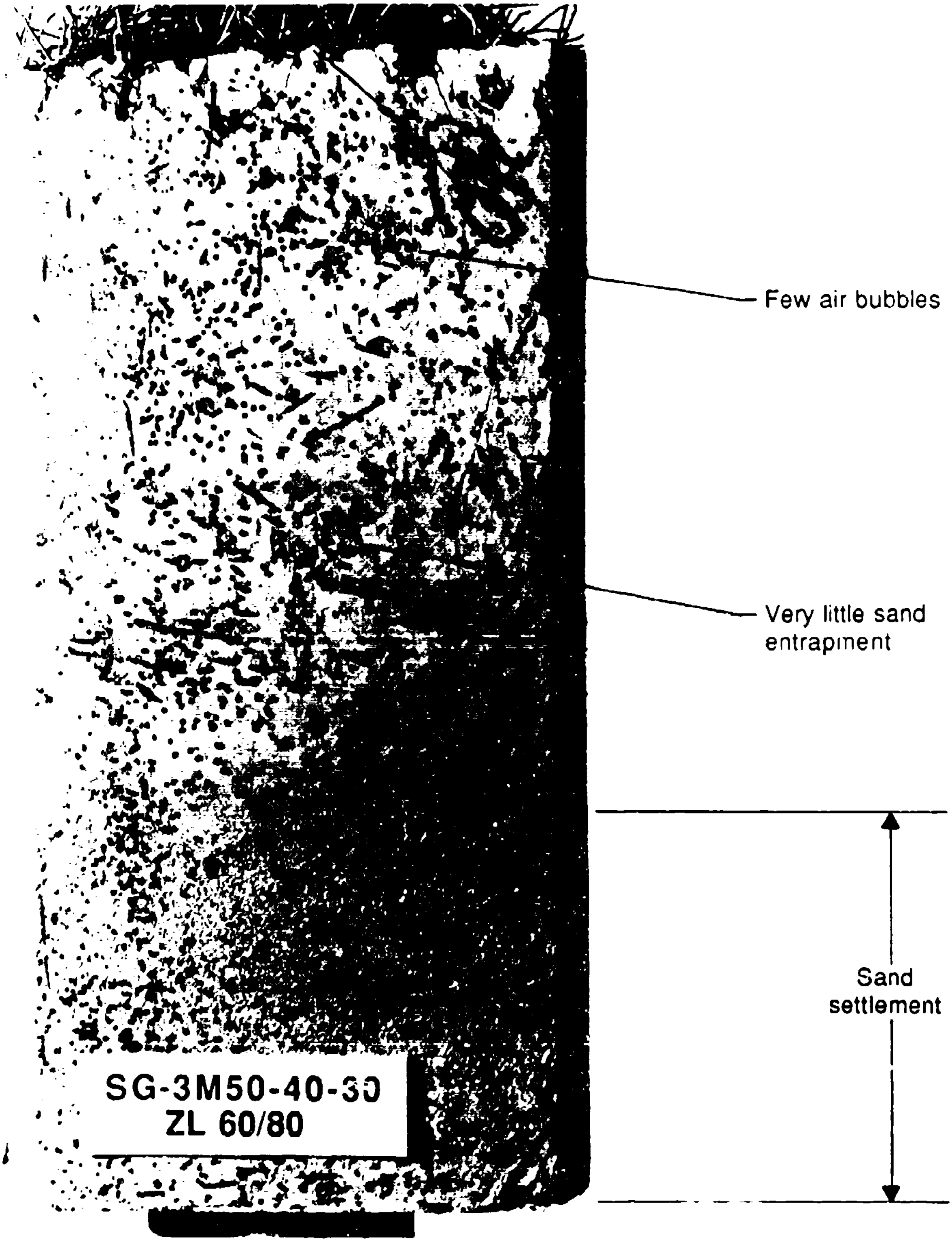


Figure A36. 30-mesh sand (50%) in fluid mix -- ZL 60/80 fibers, viscosifier.

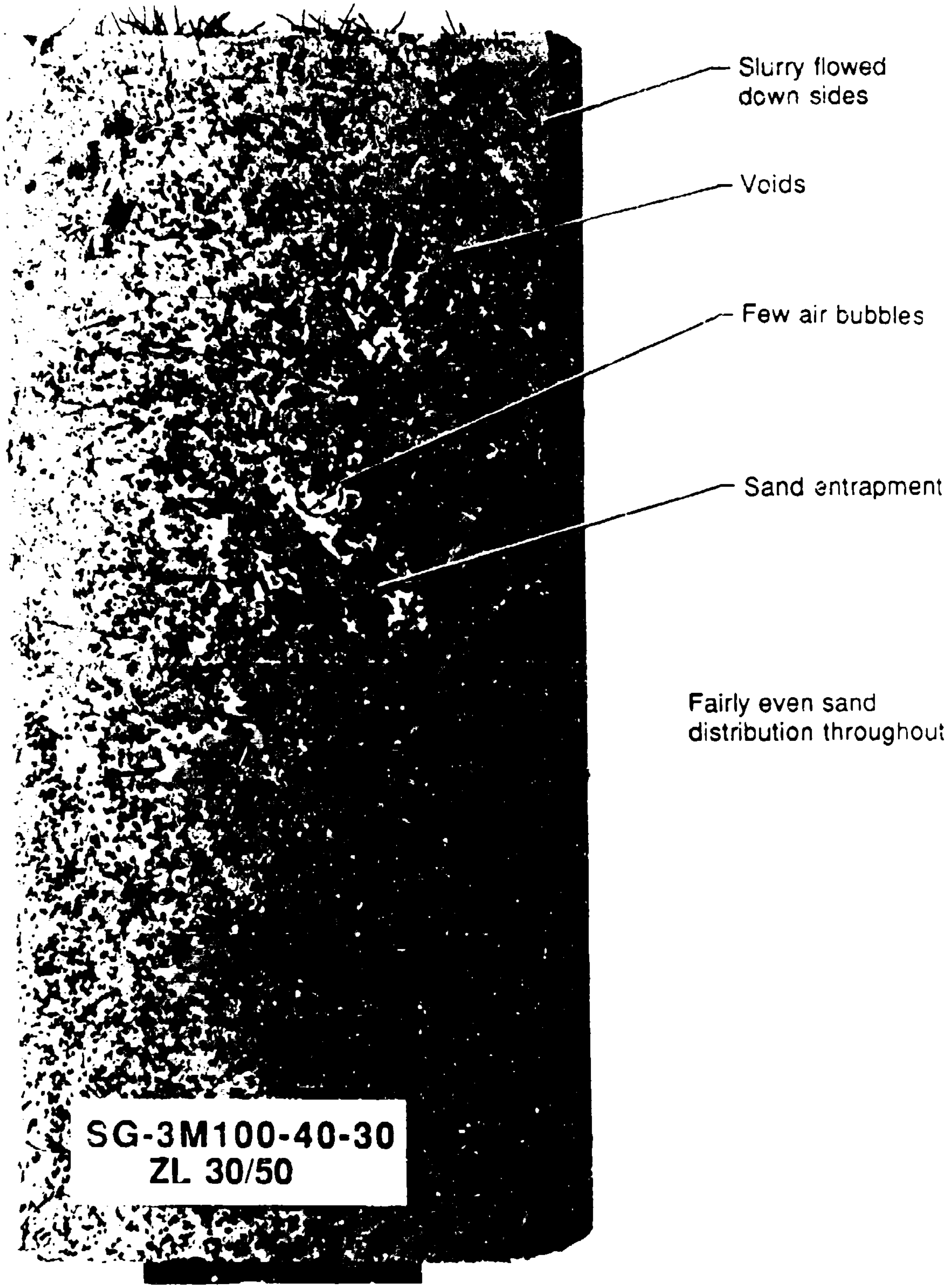


Figure A37. 30-mesh sand (100%) in fluid mix -- ZL 30/50 fibers, viscosifier, moderate vibration.

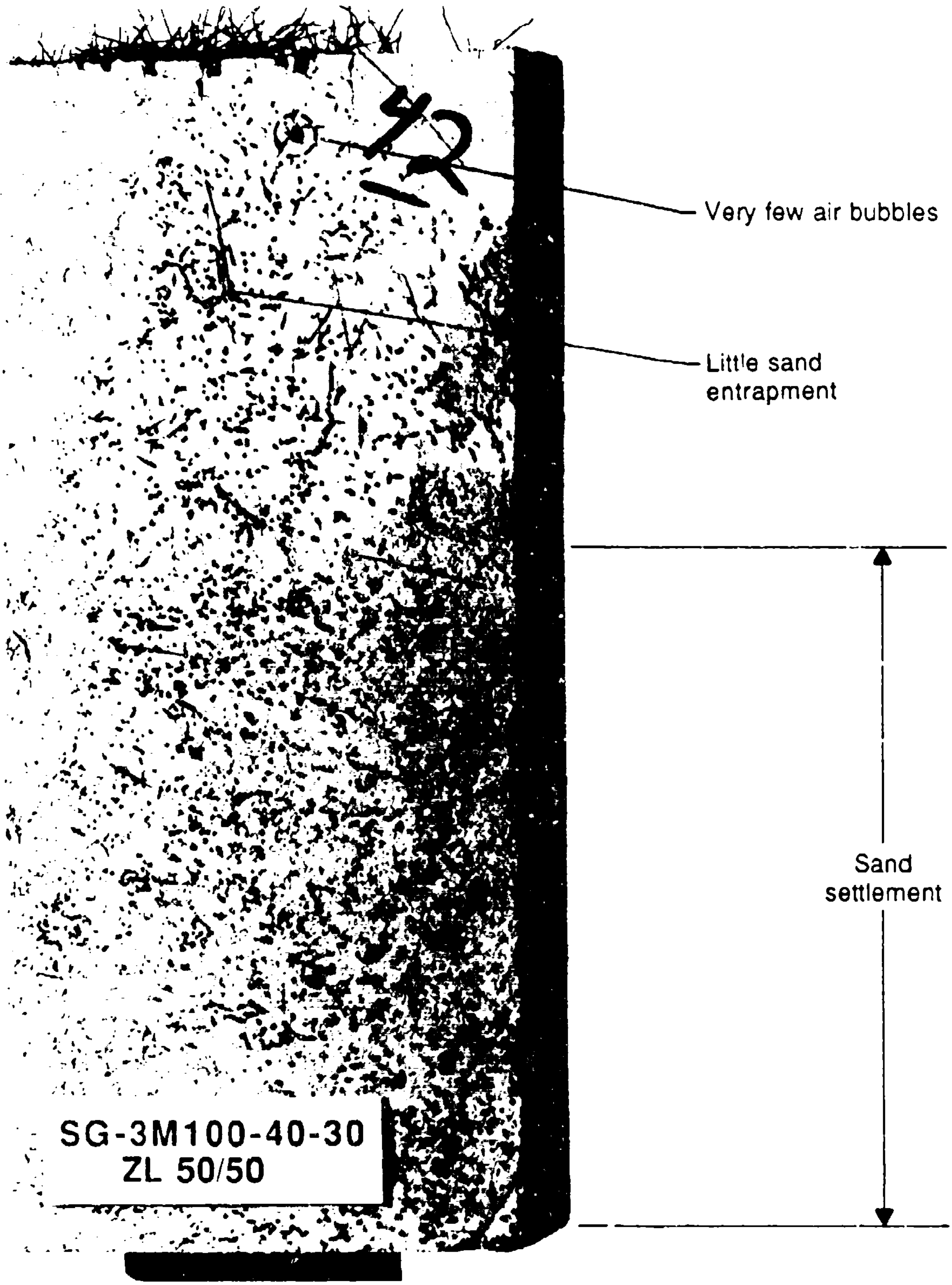


Figure A38. 30-mesh sand (100%) in fluid mix -- ZL 50/50 fibers, viscosifier.

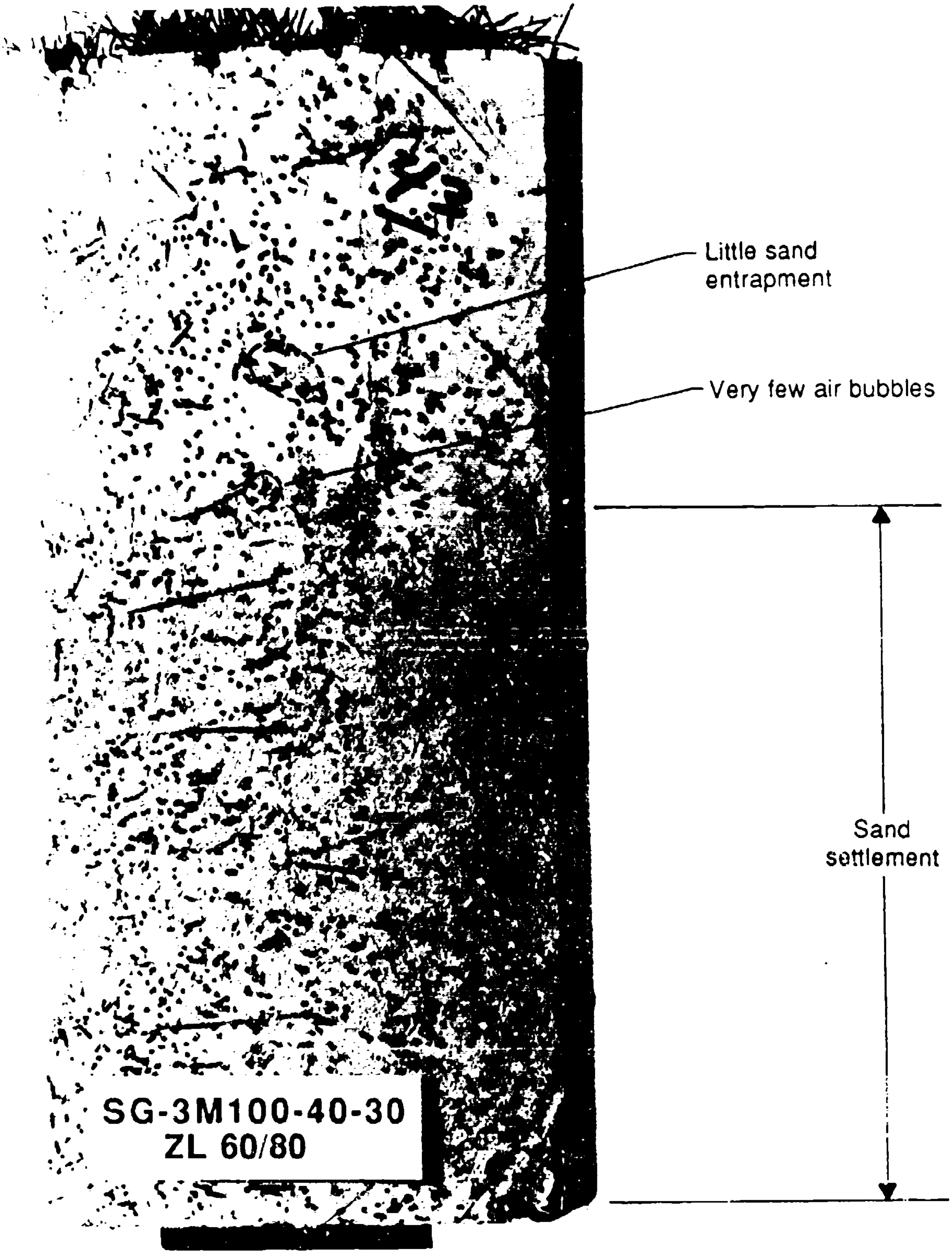


Figure A39. 30-mesh sand (100%) in fluid mix -- ZL 60/80 fibers, viscosifier.

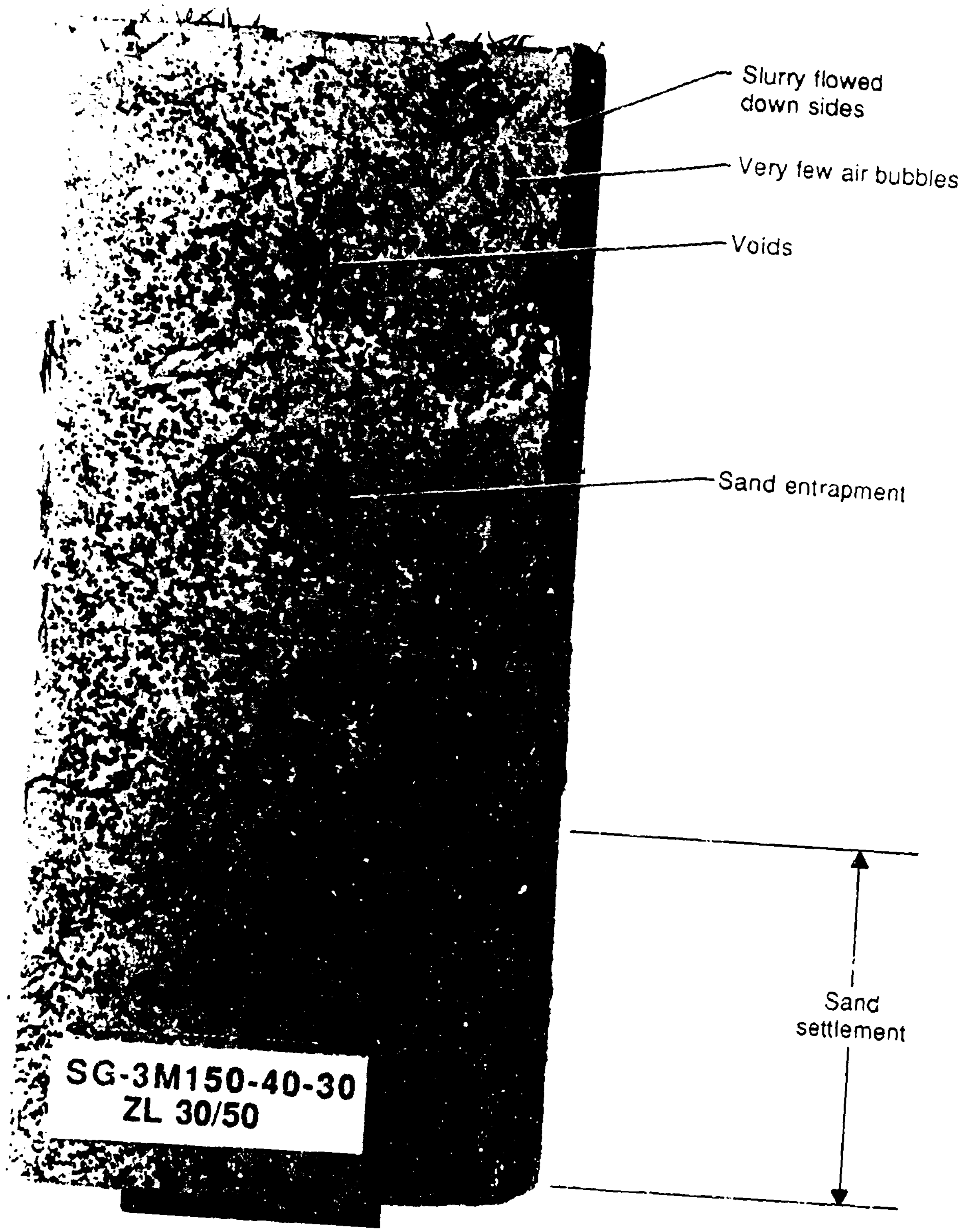


Figure A40. 30-mesh sand (150%) in fluid mix -- ZL 30/50 fibers, viscosifier, much vibration.

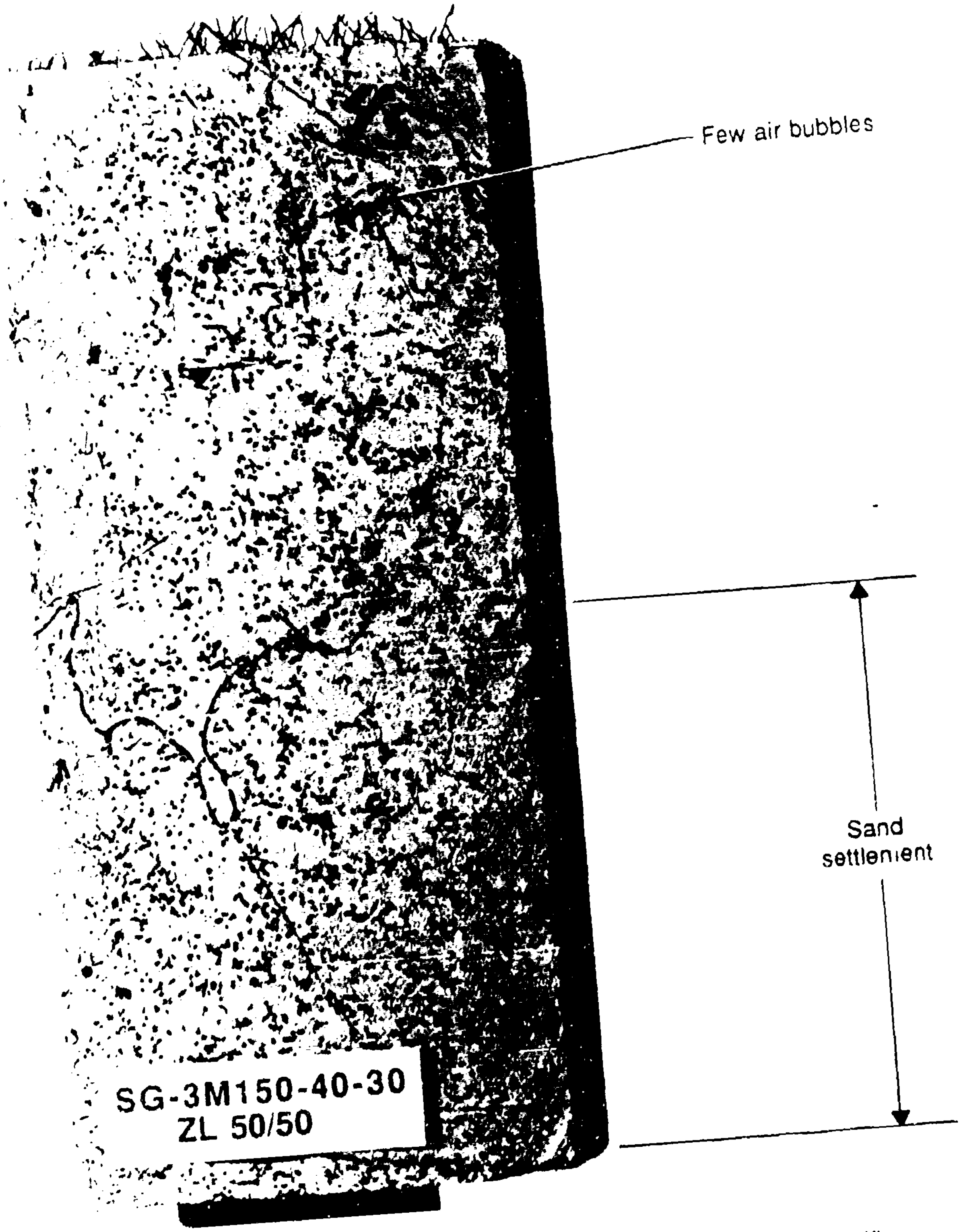


Figure A41. 30-mesh sand (150%) in fluid mix -- ZL 50/50 fibers, viscosifier.

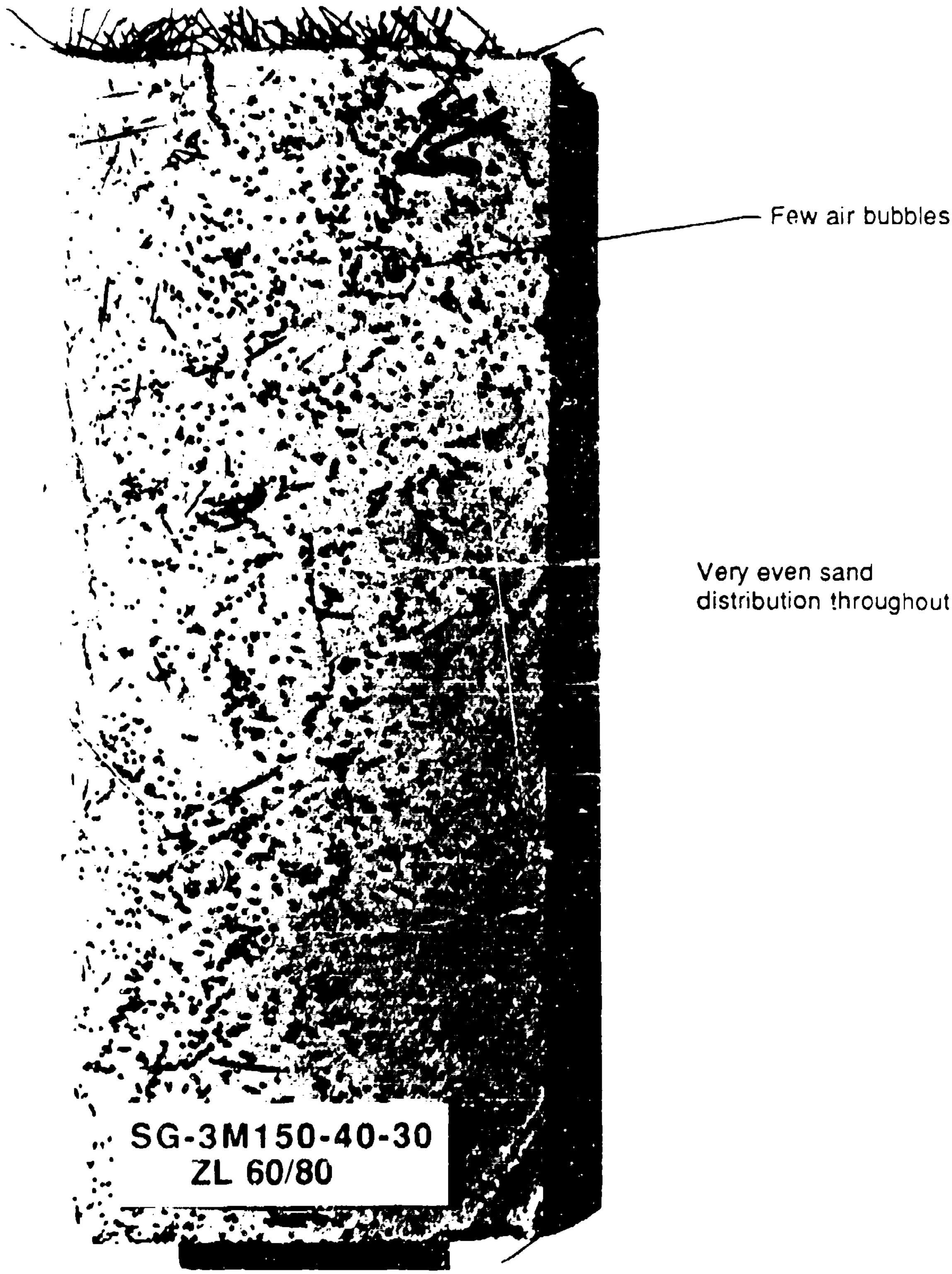


Figure A42. 30-mesh sand (150%) in fluid mix -- ZL 60/80 fibers, viscosifier.

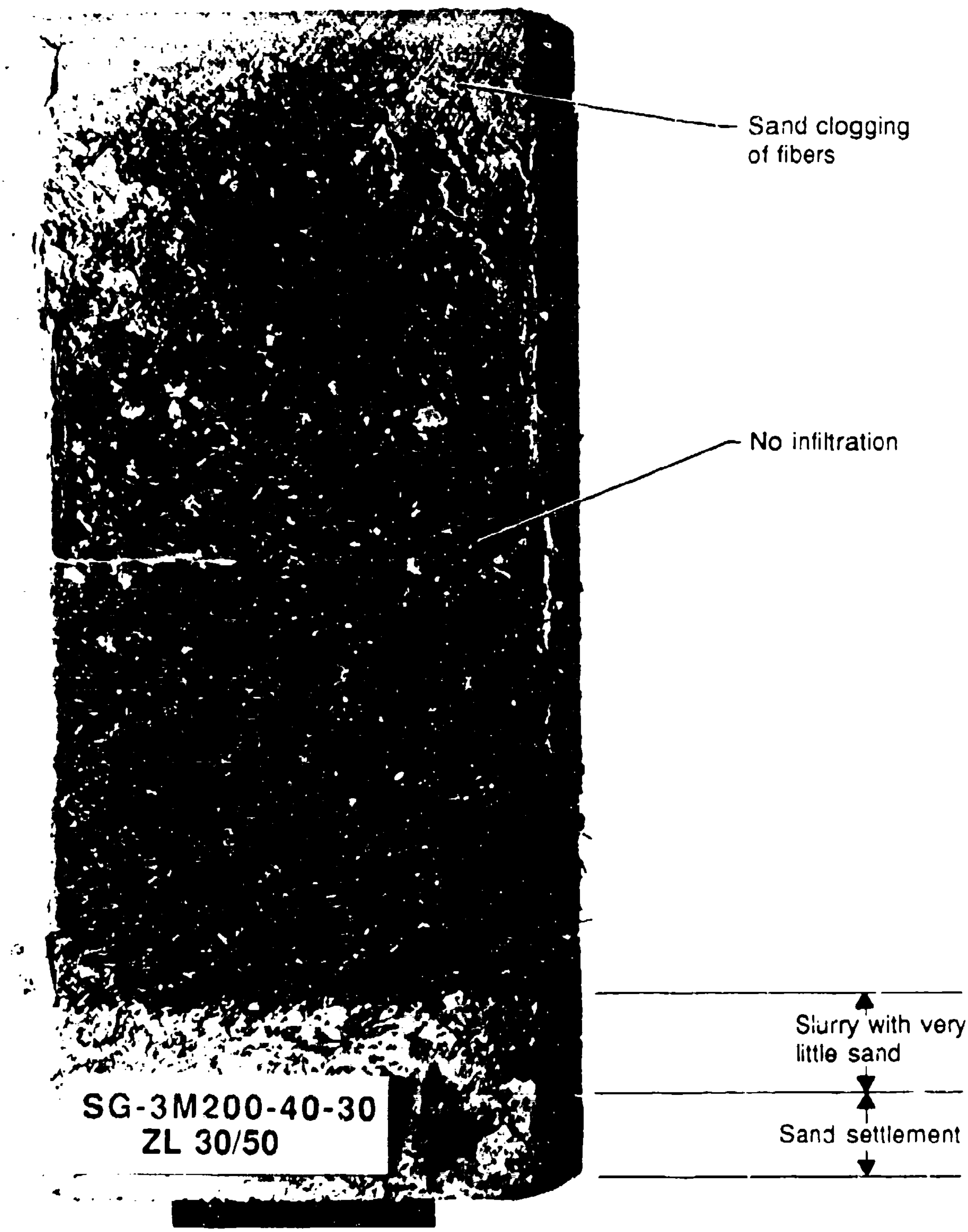


Figure A43. 30-mesh sand (200%) in fluid mix -- ZL 30/50 fibers, viscosifier, much vibration.

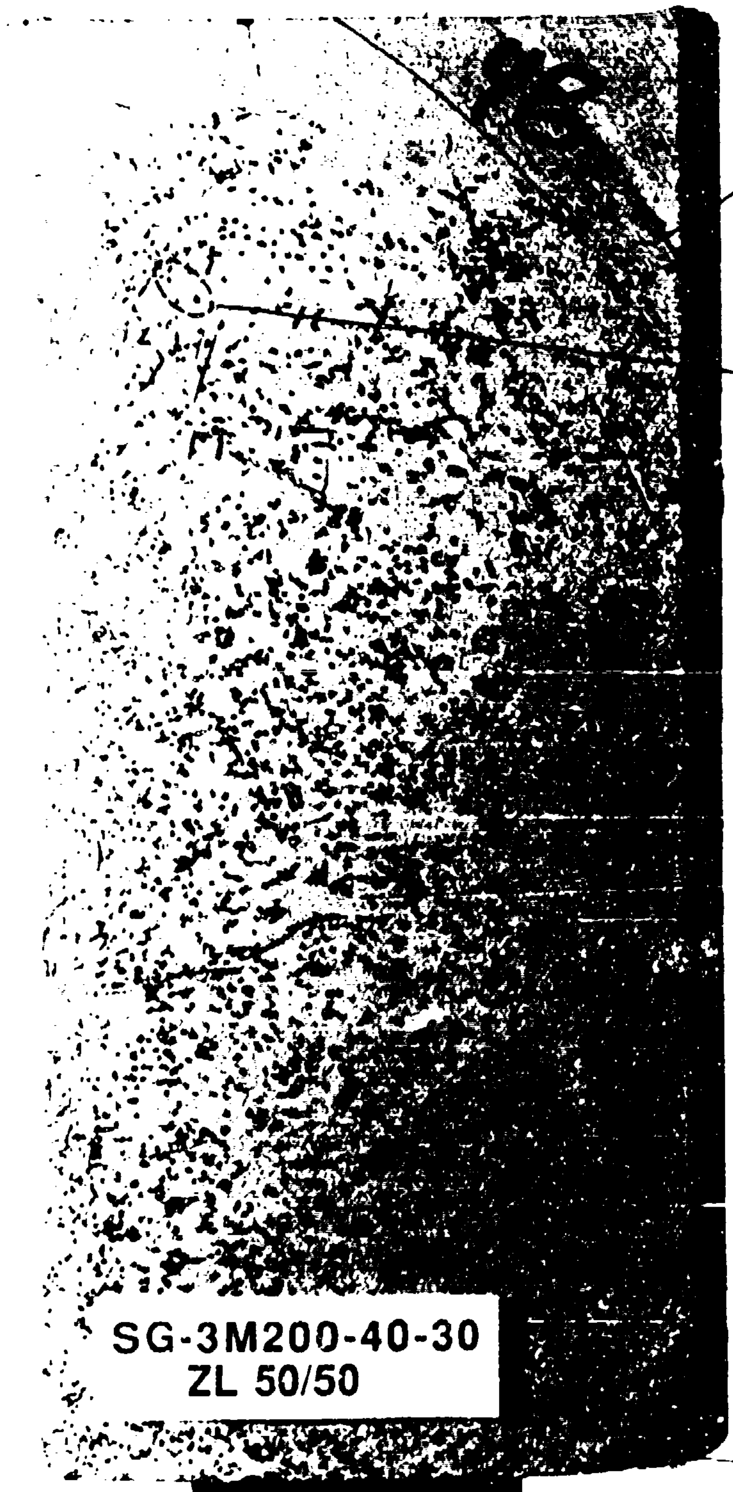


Figure A44. 30-mesh sand (200%) in fluid mix -- ZL 50/50 fibers, viscosifier, moderate vibration.

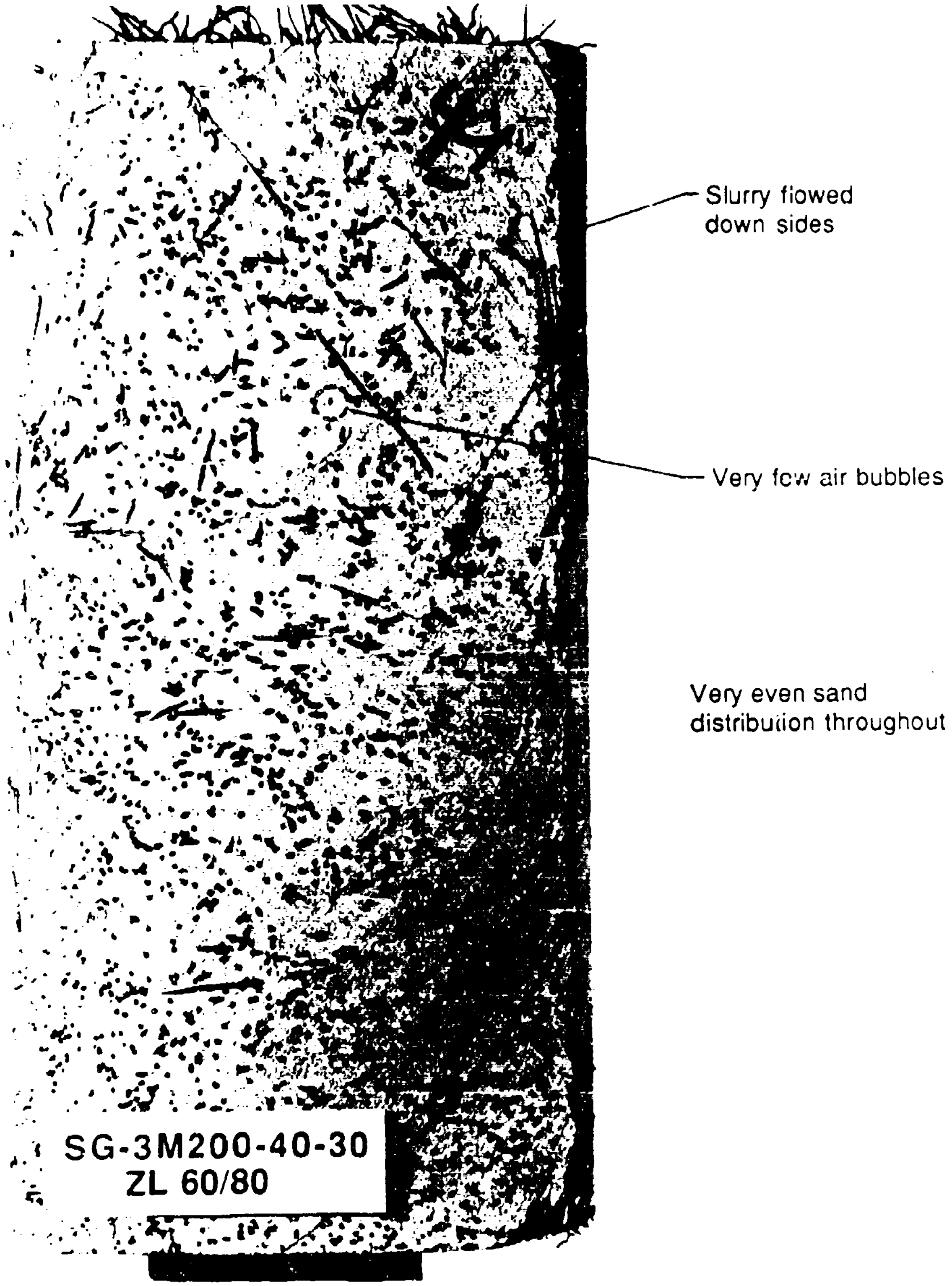


Figure A45. 30-mesh sand (200%) in fluid mix -- ZL 60/80 fibers, viscosifier, little vibration.

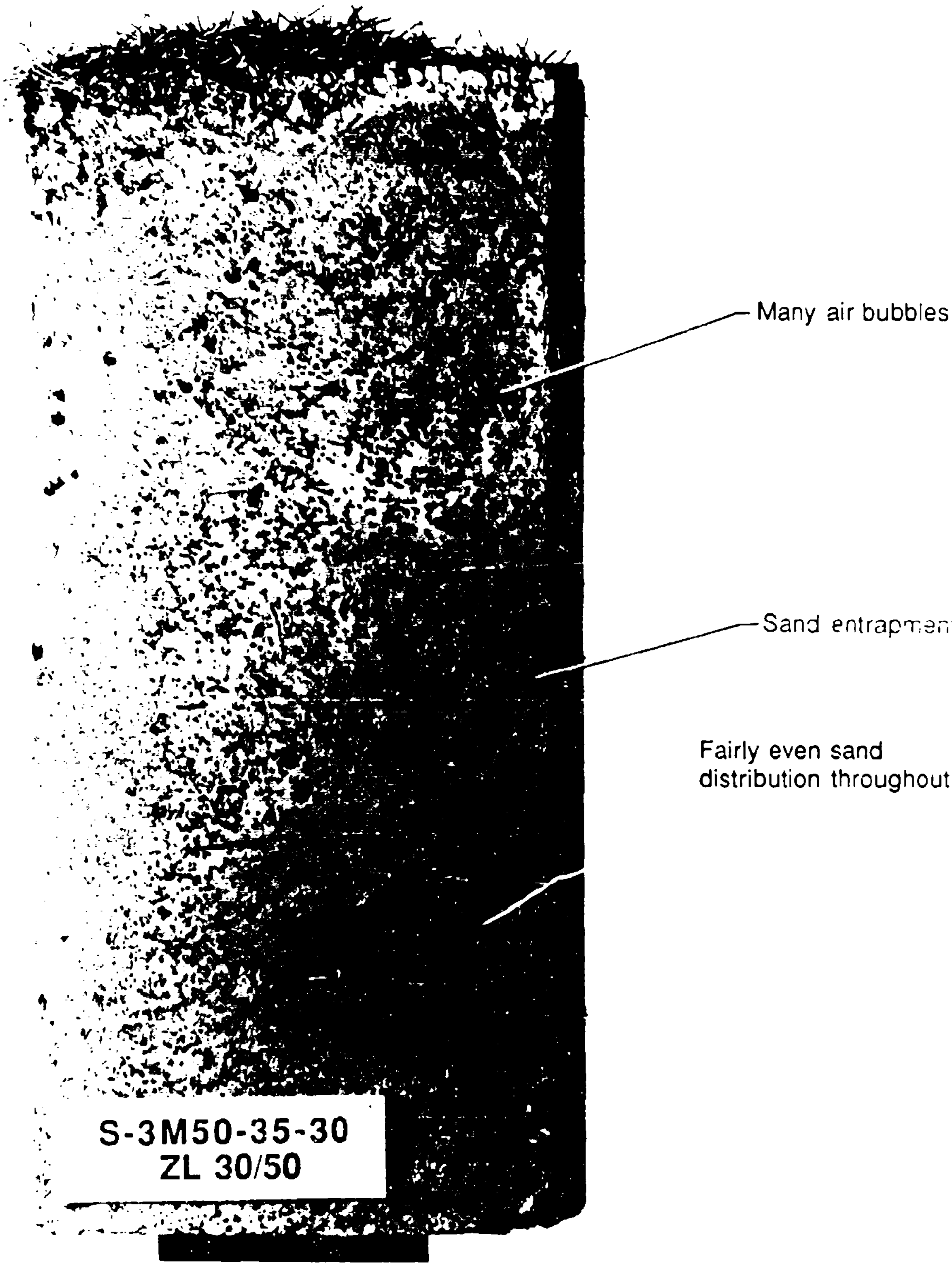


Figure A46. 30-mesh sand (50%) in moderately viscous mix -- ZL 30/50 fibers.

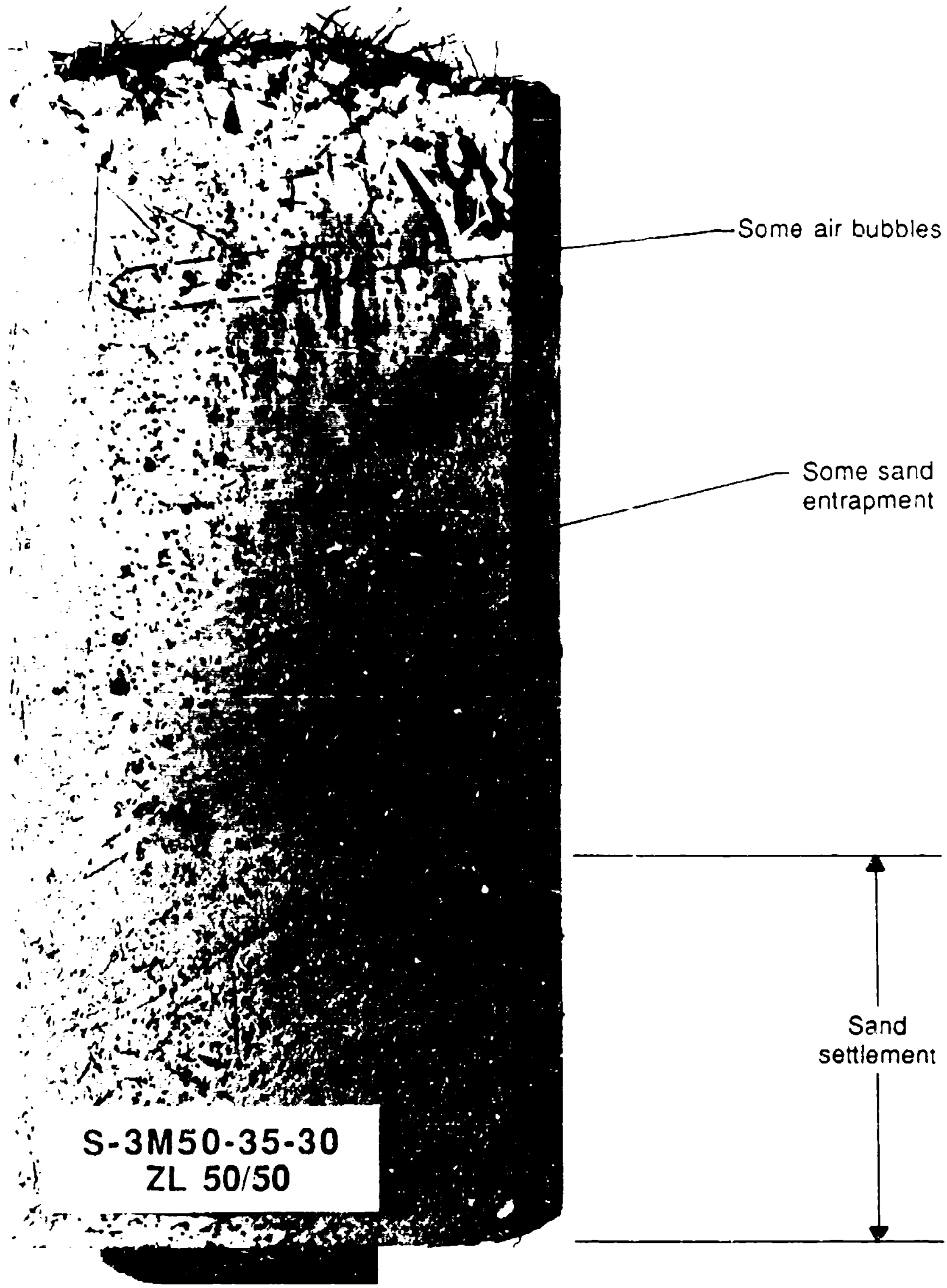


Figure A47. 30-mesh sand (50%) in moderately viscous mix -- ZL 50/50 fibers.

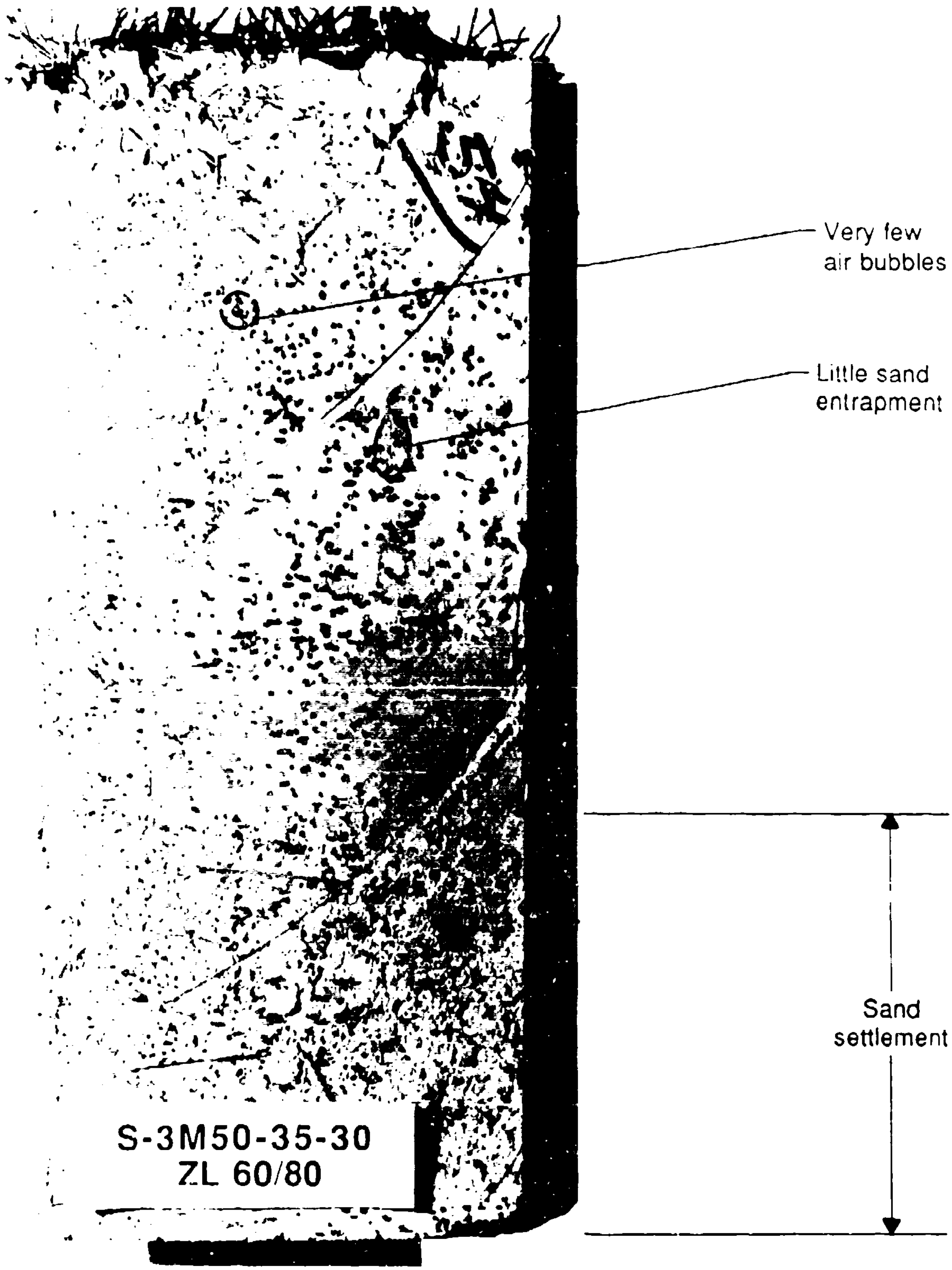


Figure A48. 30-mesh sand (50%) in moderately viscous mix -- ZL 60/80 fibers.

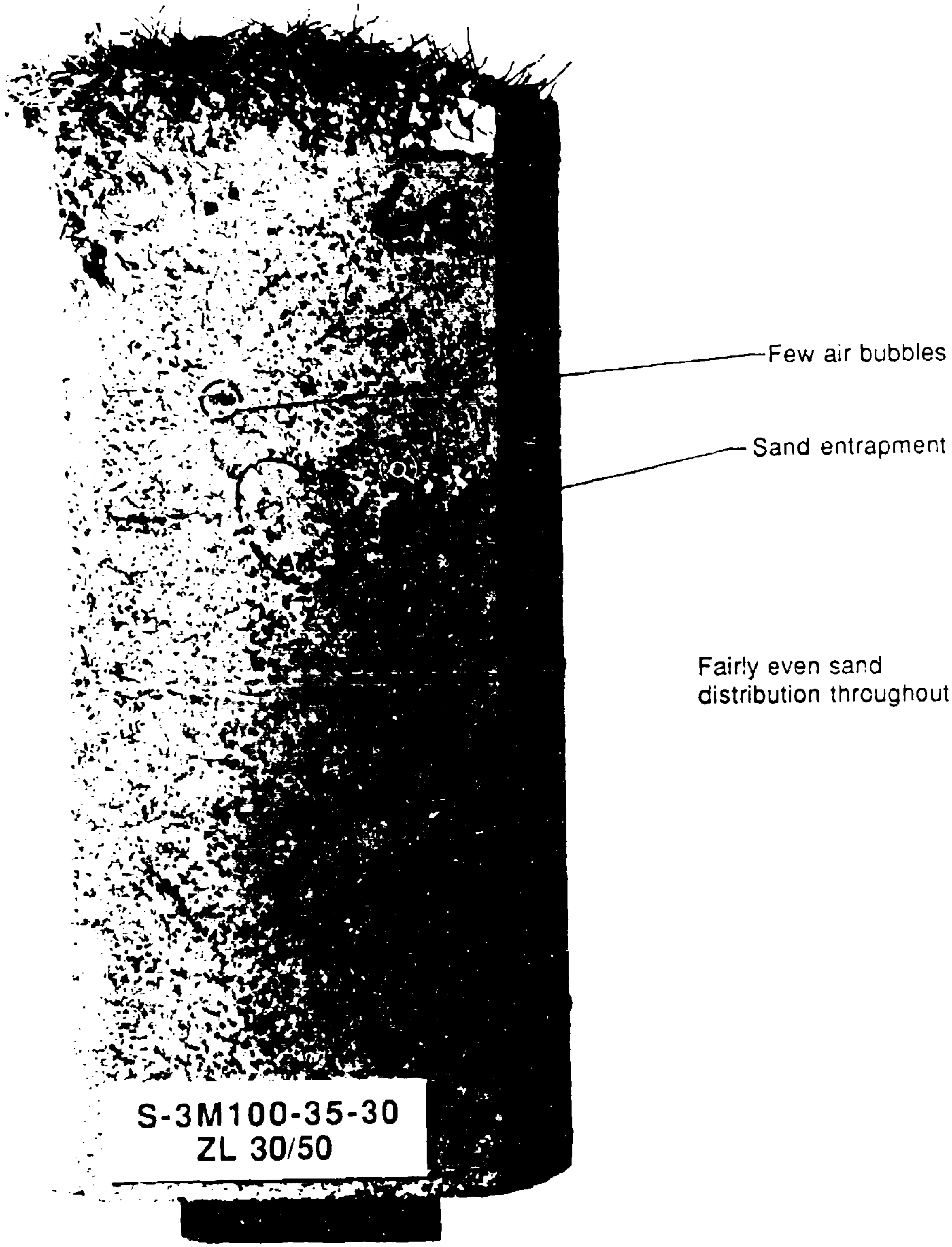


Figure A49. 30-mesh sand (100%) in moderately viscous mix -- ZL 30/50 fibers

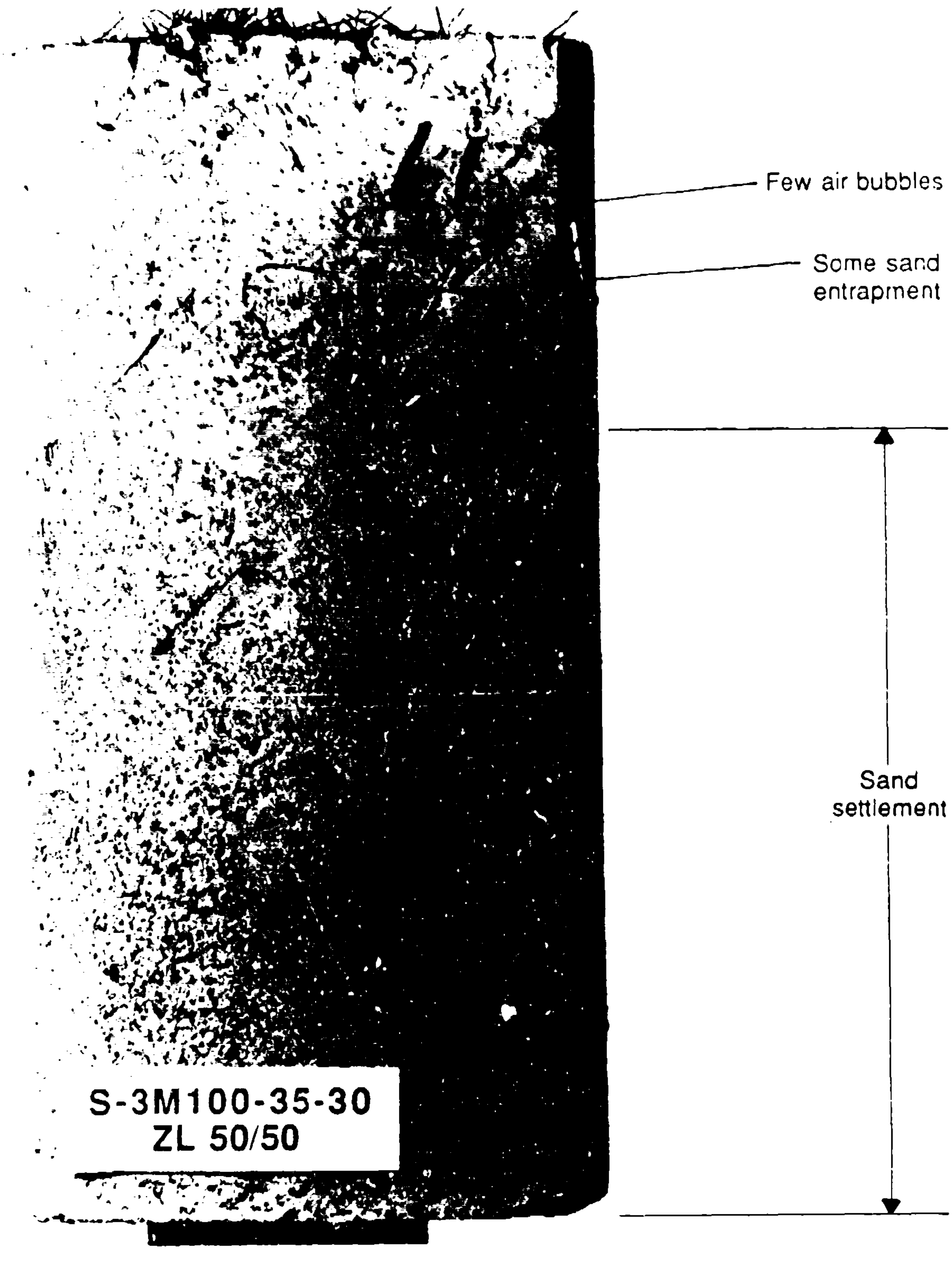


Figure A50. 30-mesh sand (100%) in moderately viscous mix -- ZL 50/50 fibers.

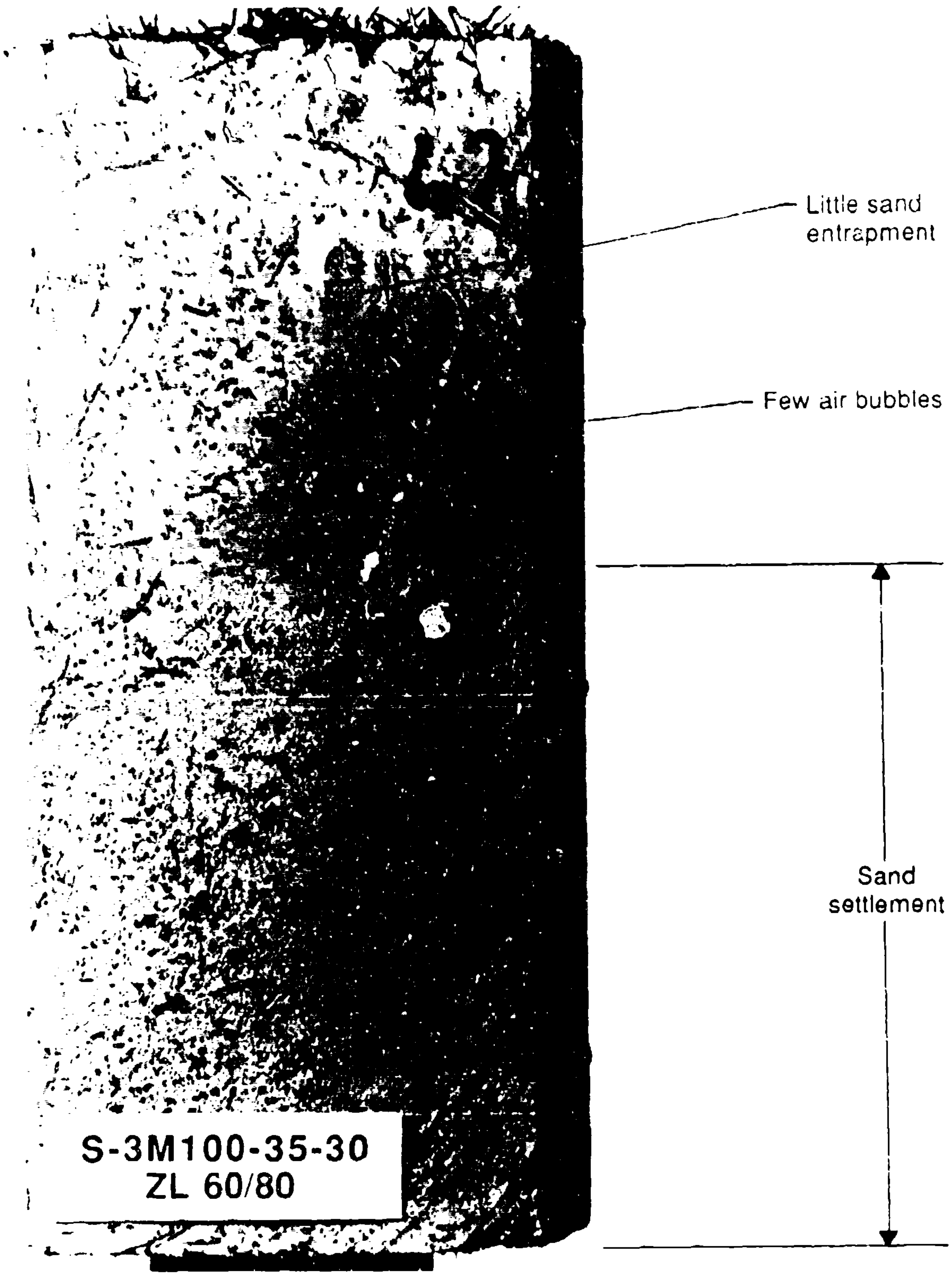


Figure A51. 30-mesh sand (100%) in moderately viscous mix -- ZL 60/80 fibers.

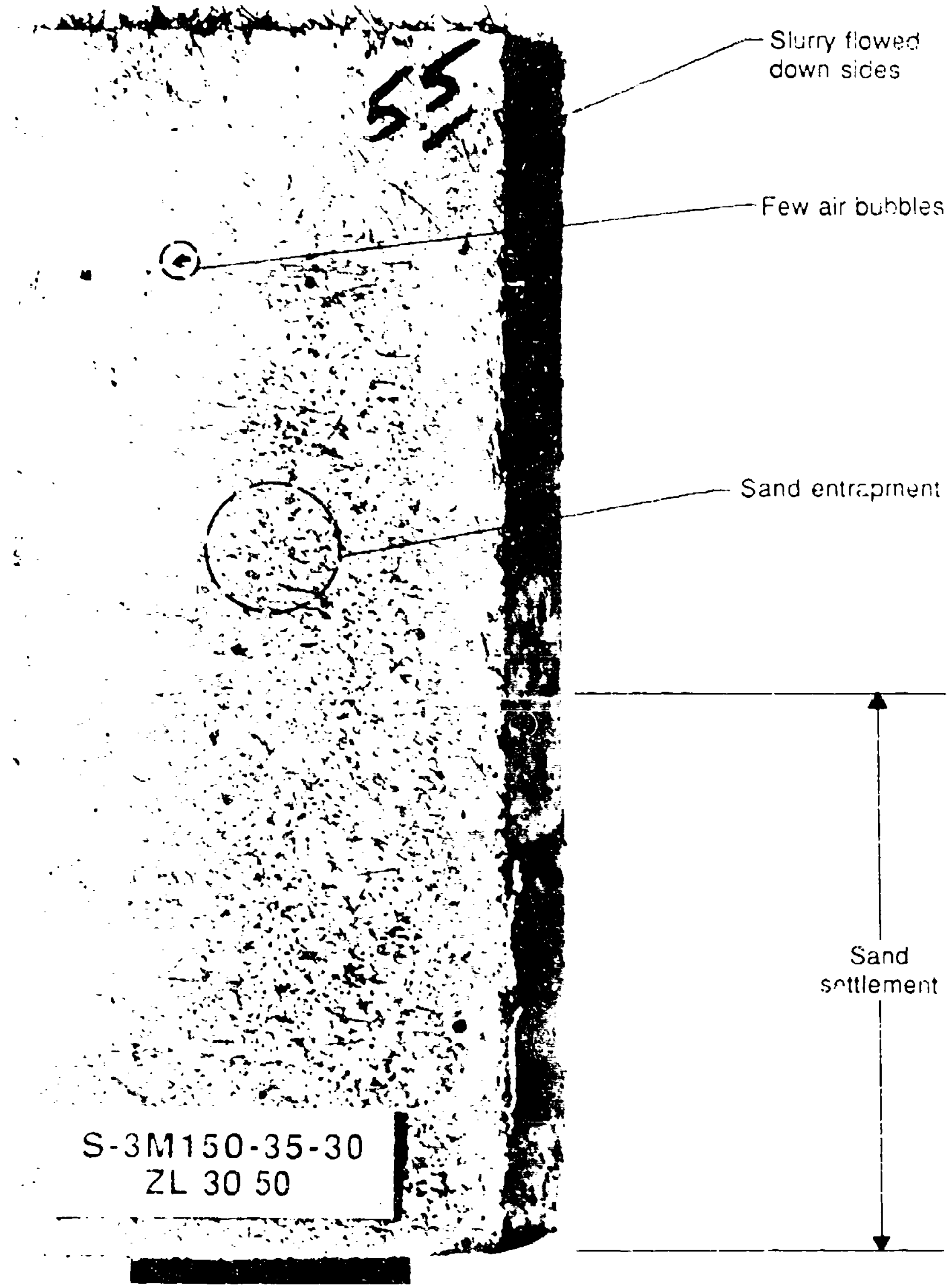


Figure A52. 30-mesh sand (150%) in moderately viscous mix -- ZL 30/50 fibers, moderate vibration.

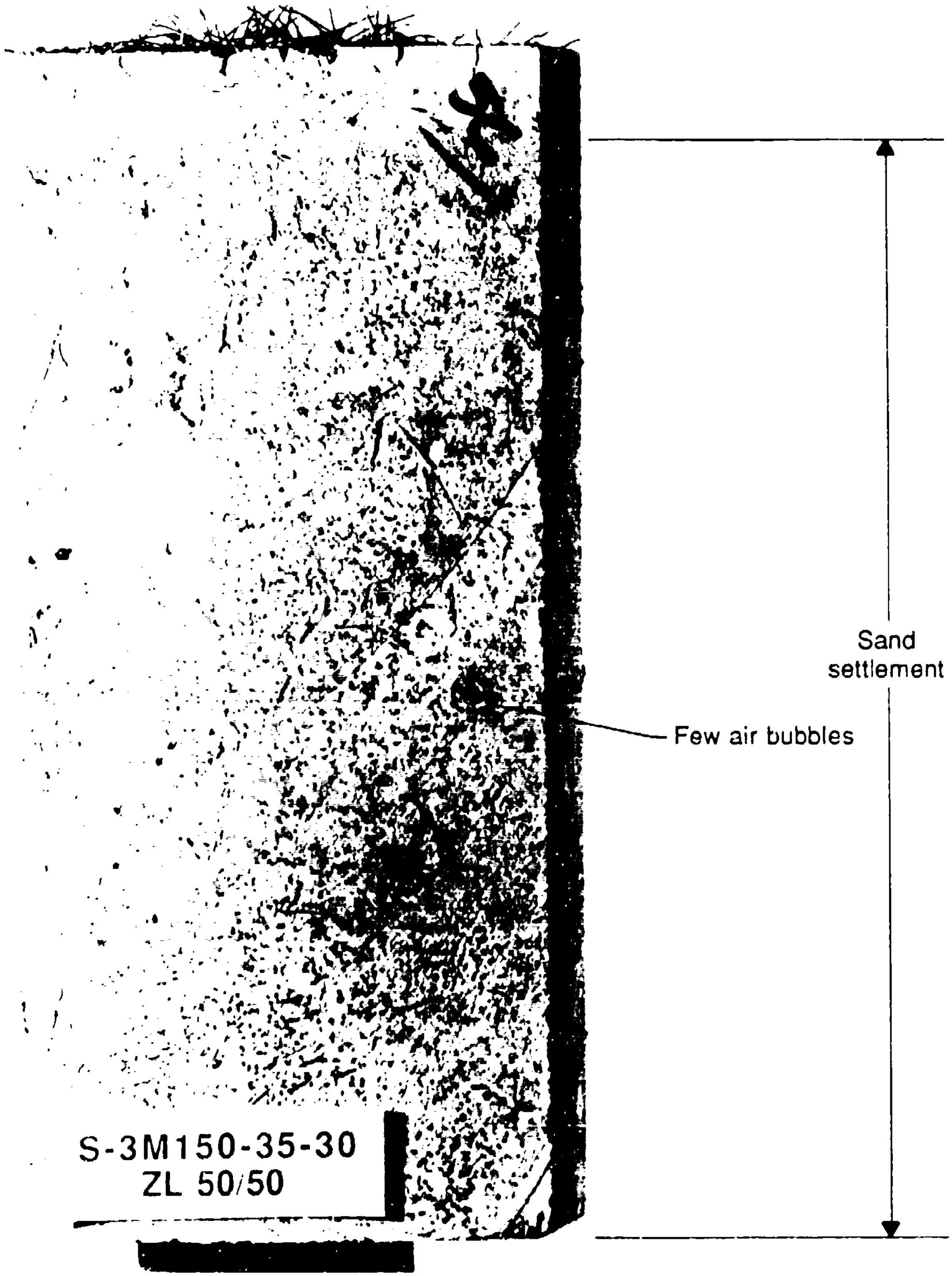


Figure A53. 30-mesh sand (150%) in moderately viscous mix -- ZL 50/50 fibers.

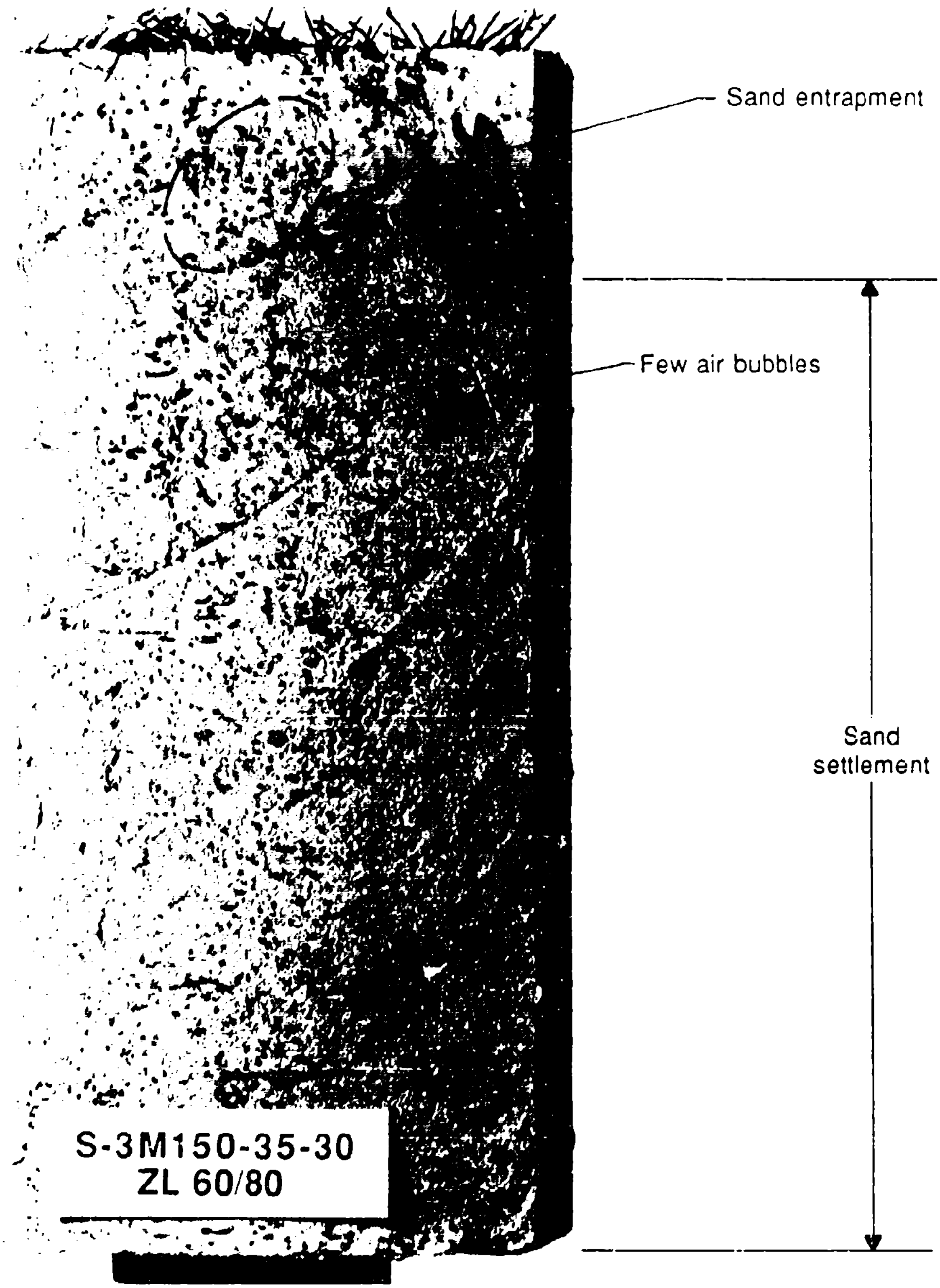


Figure A54. 30-mesh sand (150%) in moderately viscous mix -- ZL 60/80 fibers.

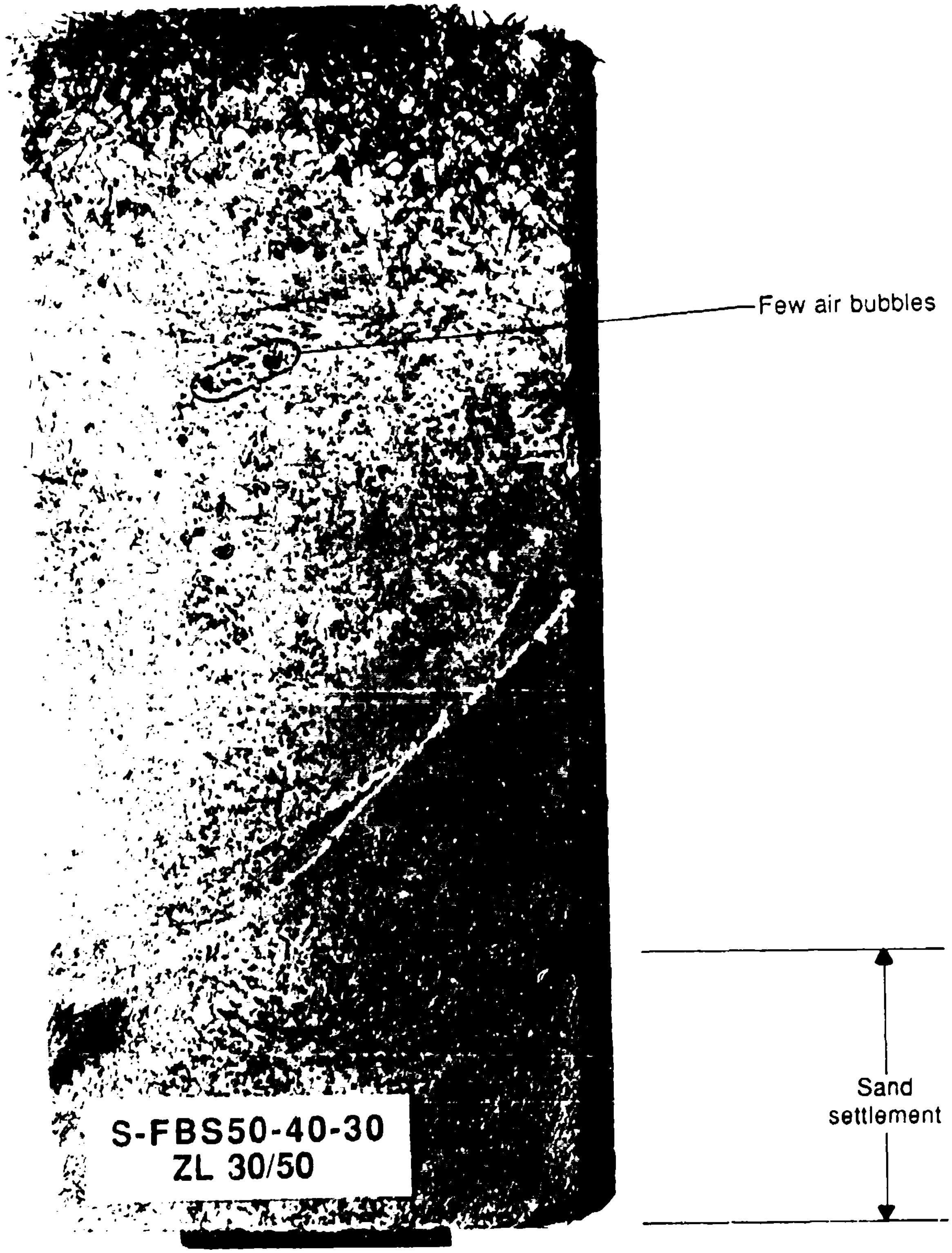


Figure A55. Fine blasting sand (50%) in fluid mix -- ZL 30/50 fibers.

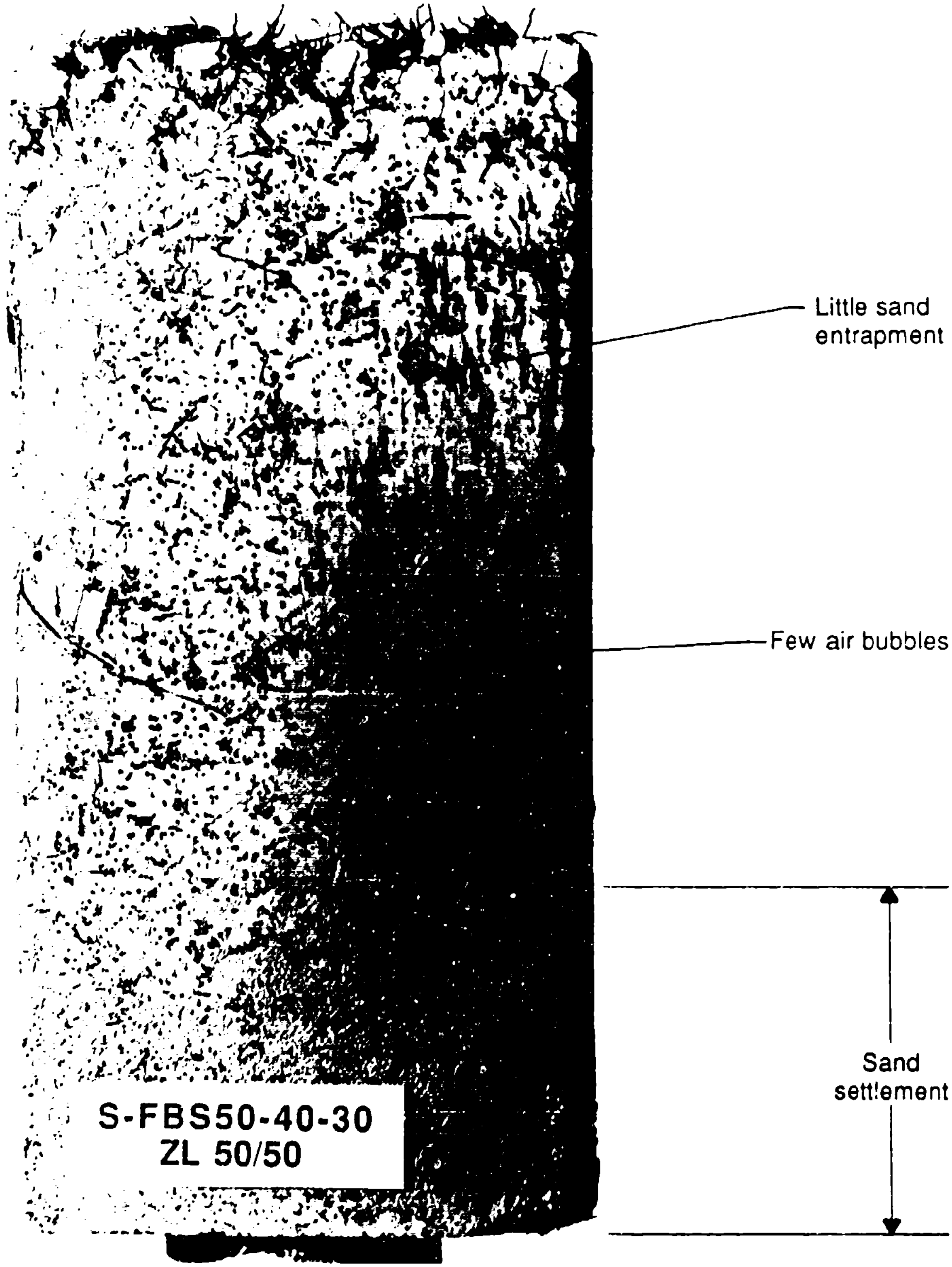


Figure A56. Fine blasting sand (50%) in fluid mix -- ZL 50/50 fibers.

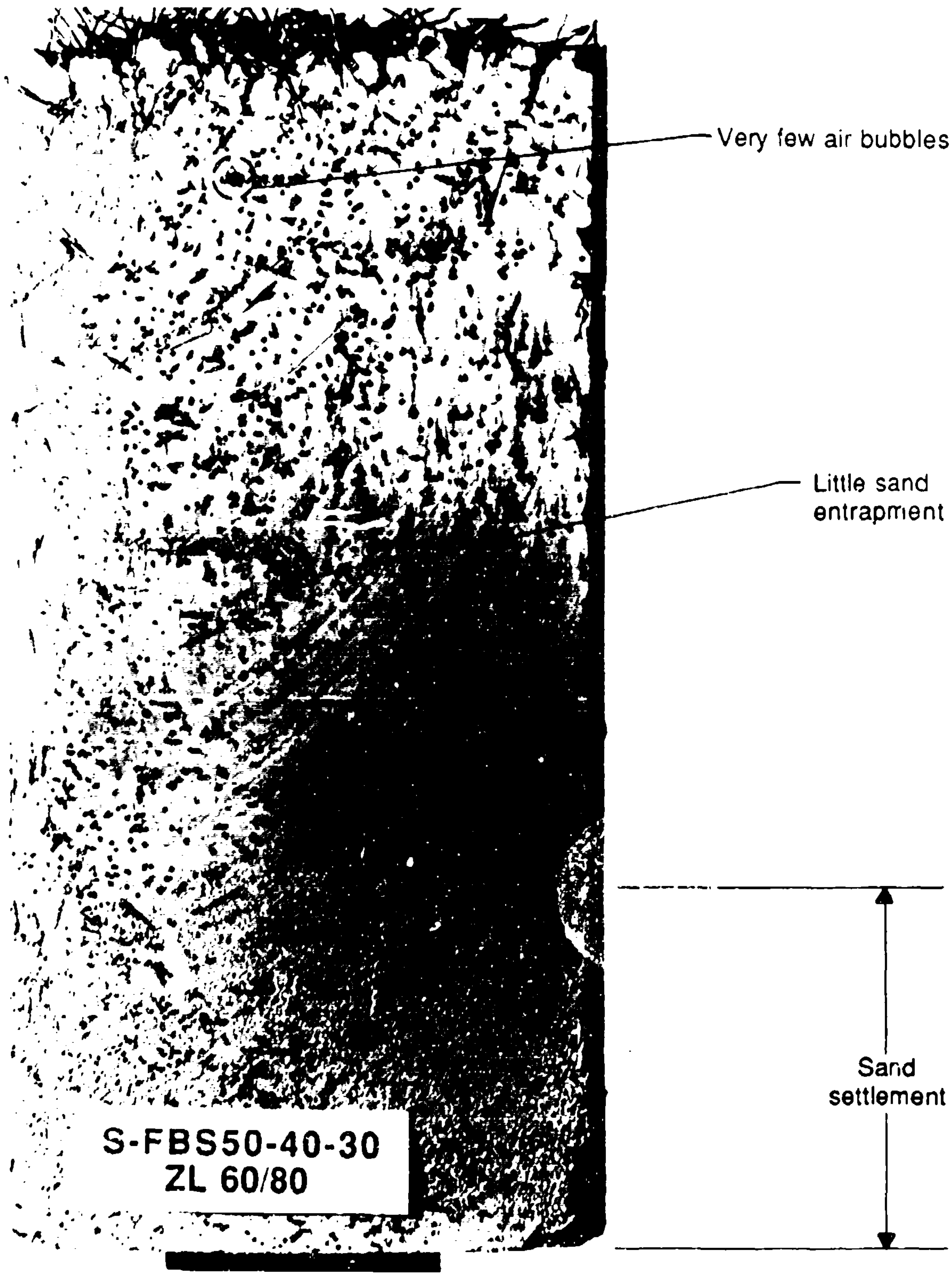


Figure A57. Fine blasting sand (50%) in fluid mix -- ZL 60/80 fibers.

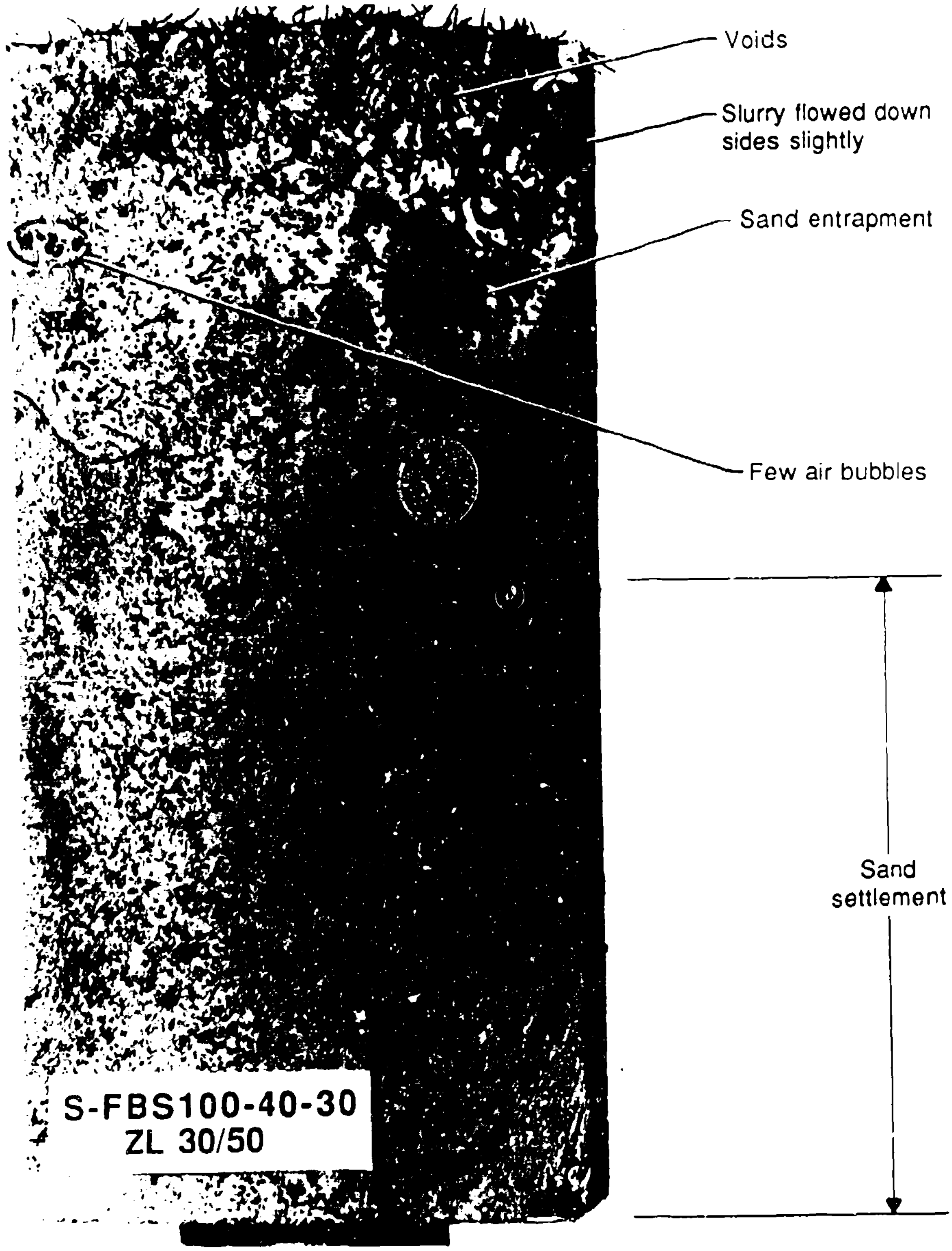


Figure A58. Fine blasting sand (100%) in fluid mix -- ZL 30/50 fibers.

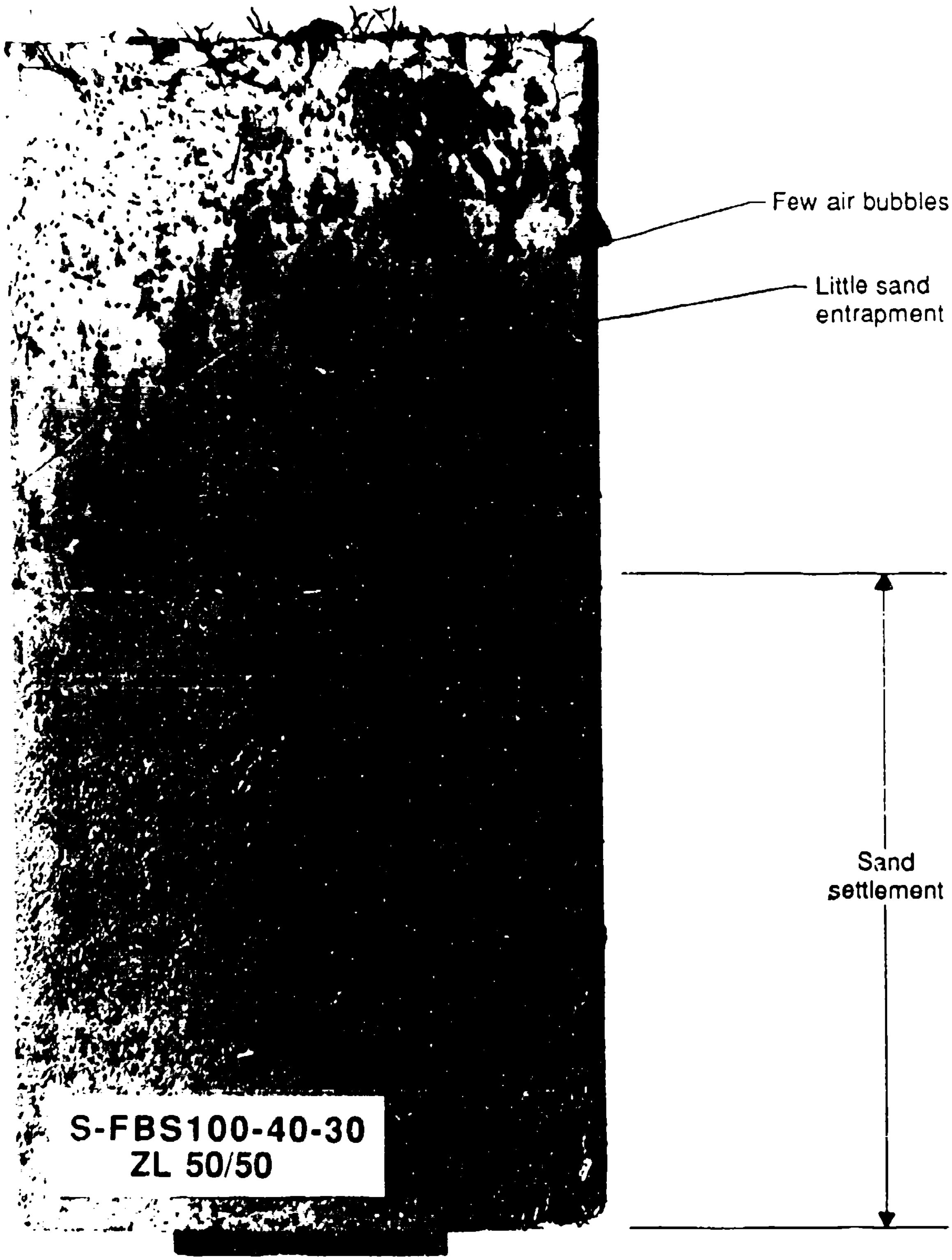


Figure A59. Fine blasting sand (100%) in fluid mix -- ZL 50/50 fibers.

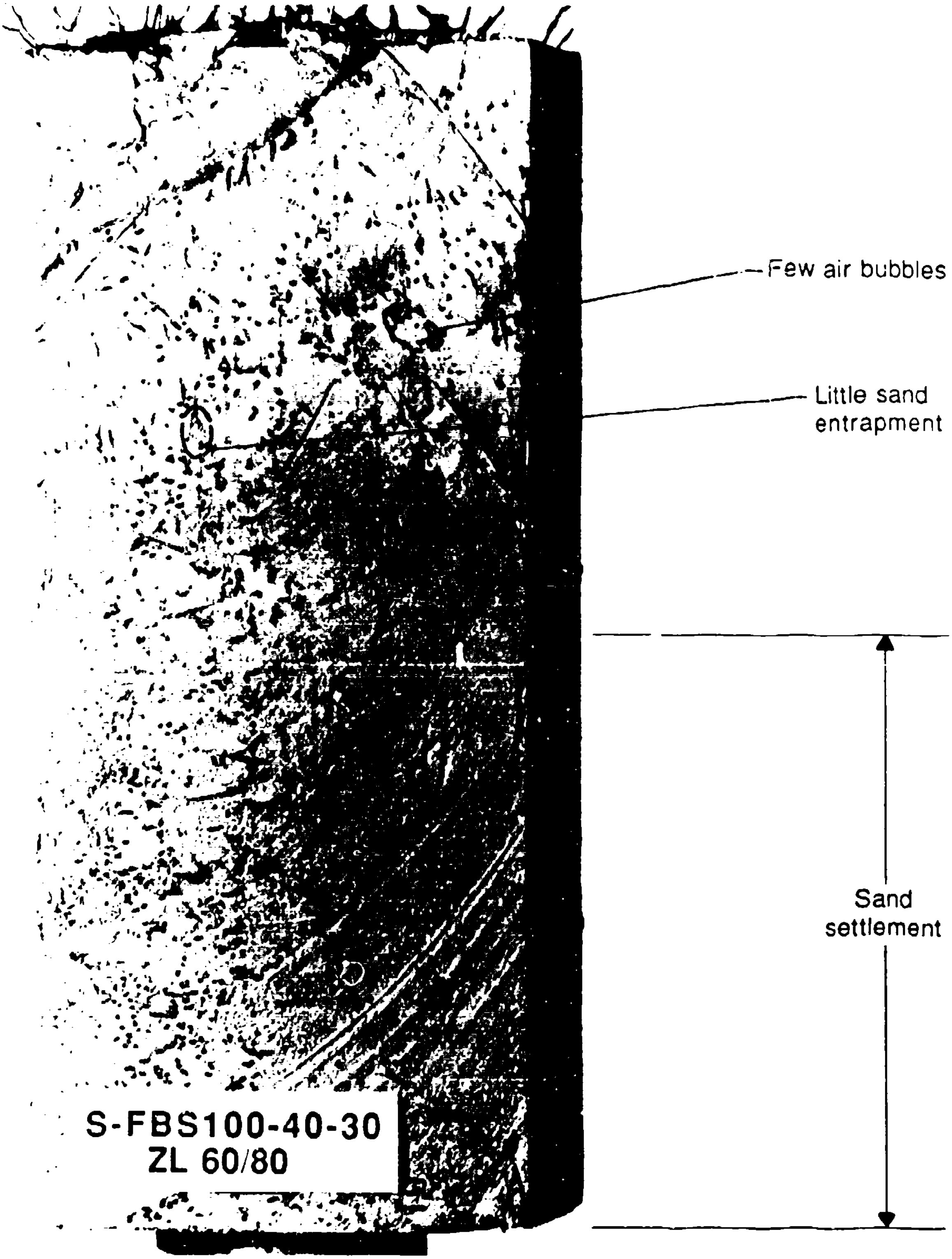


Figure A60. Fine blasting sand (100%) in fluid mix -- ZL 60/80 fibers.

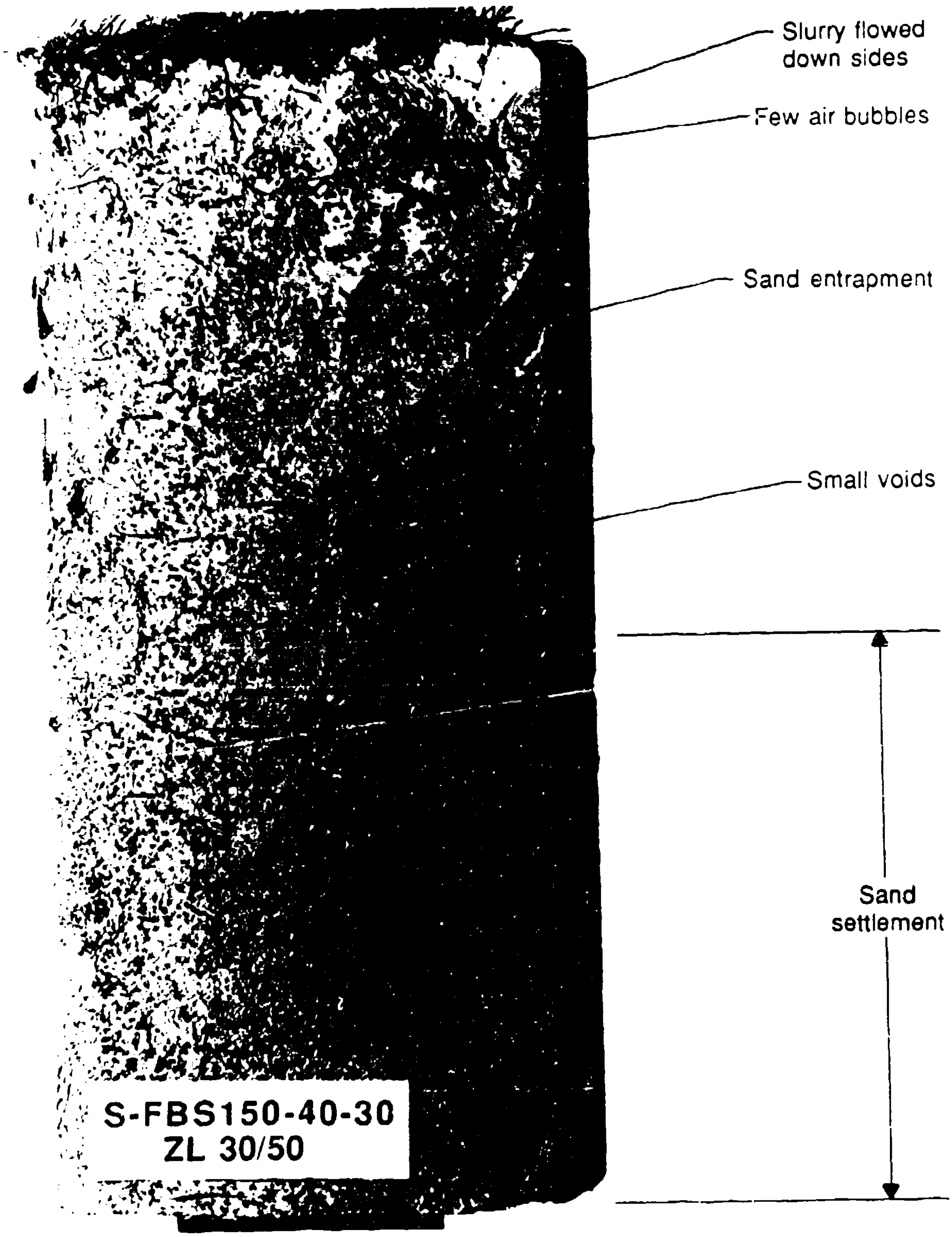


Figure A61. Fine blasting sand (150%) in fluid mix -- ZL 30/50 fibers, much vibration.

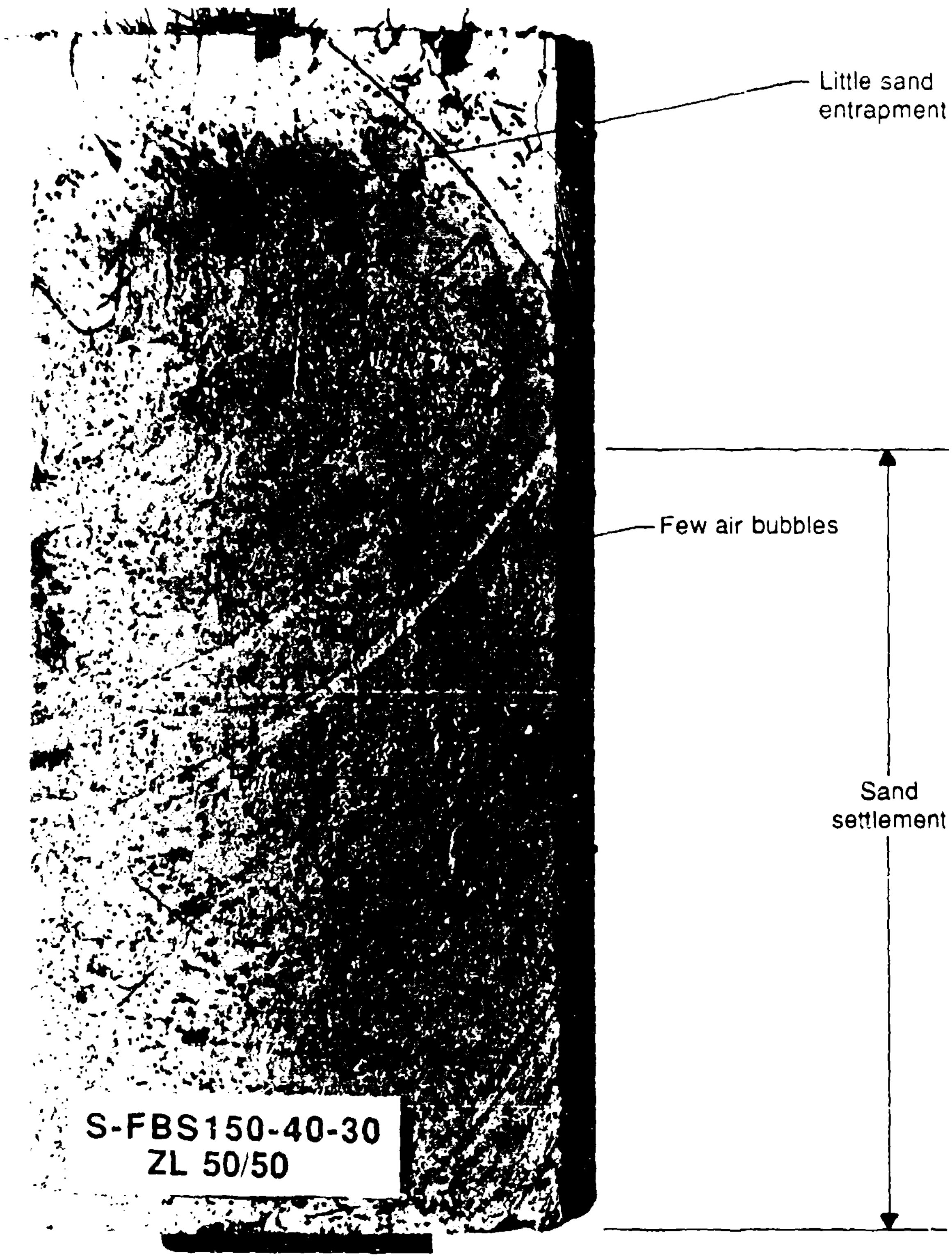


Figure A62. Fine blasting sand (150%) in fluid mix -- ZL 50/50 fibers.

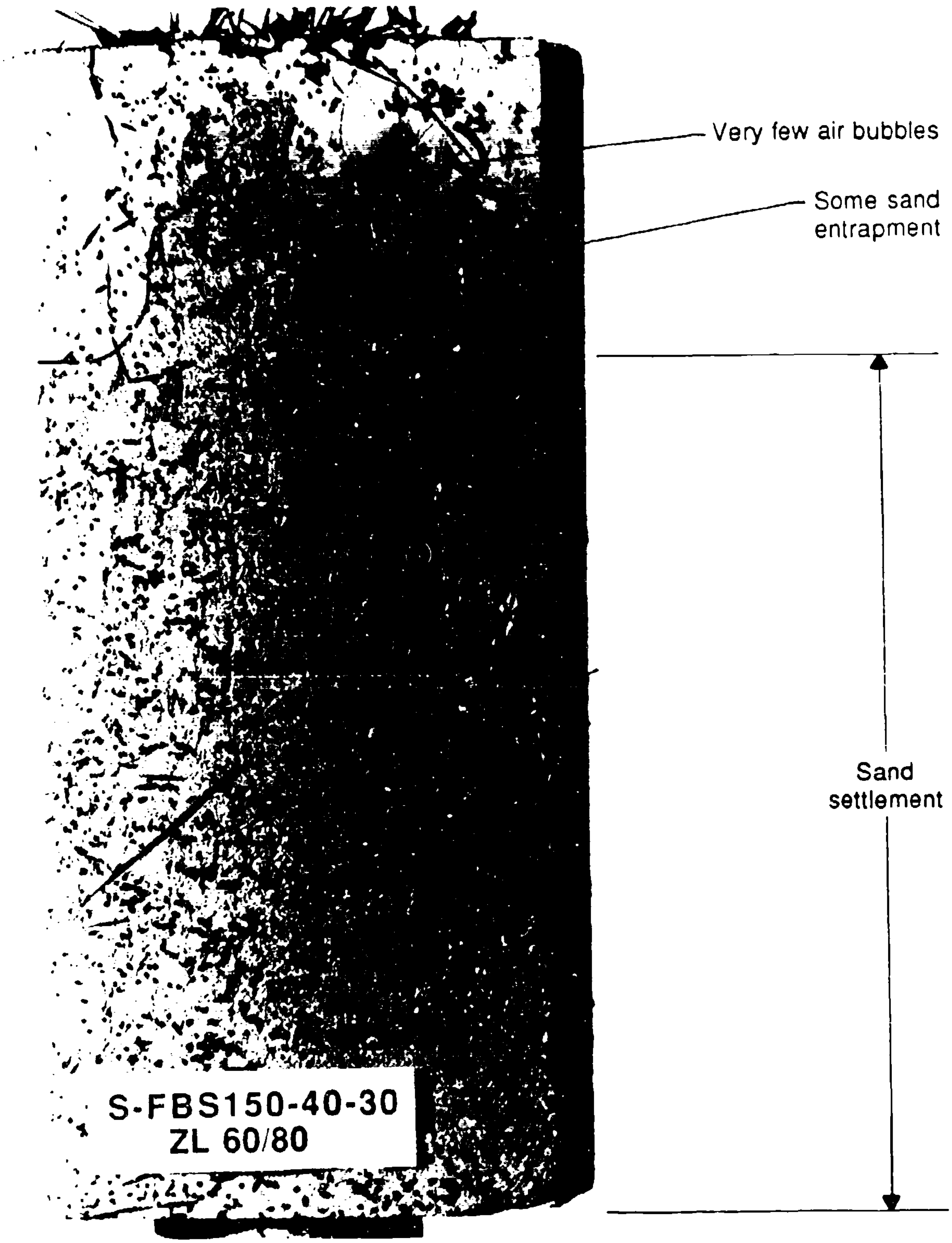


Figure A63. Fine blasting sand (150%) in fluid mix -- ZL 60/80 fibers.

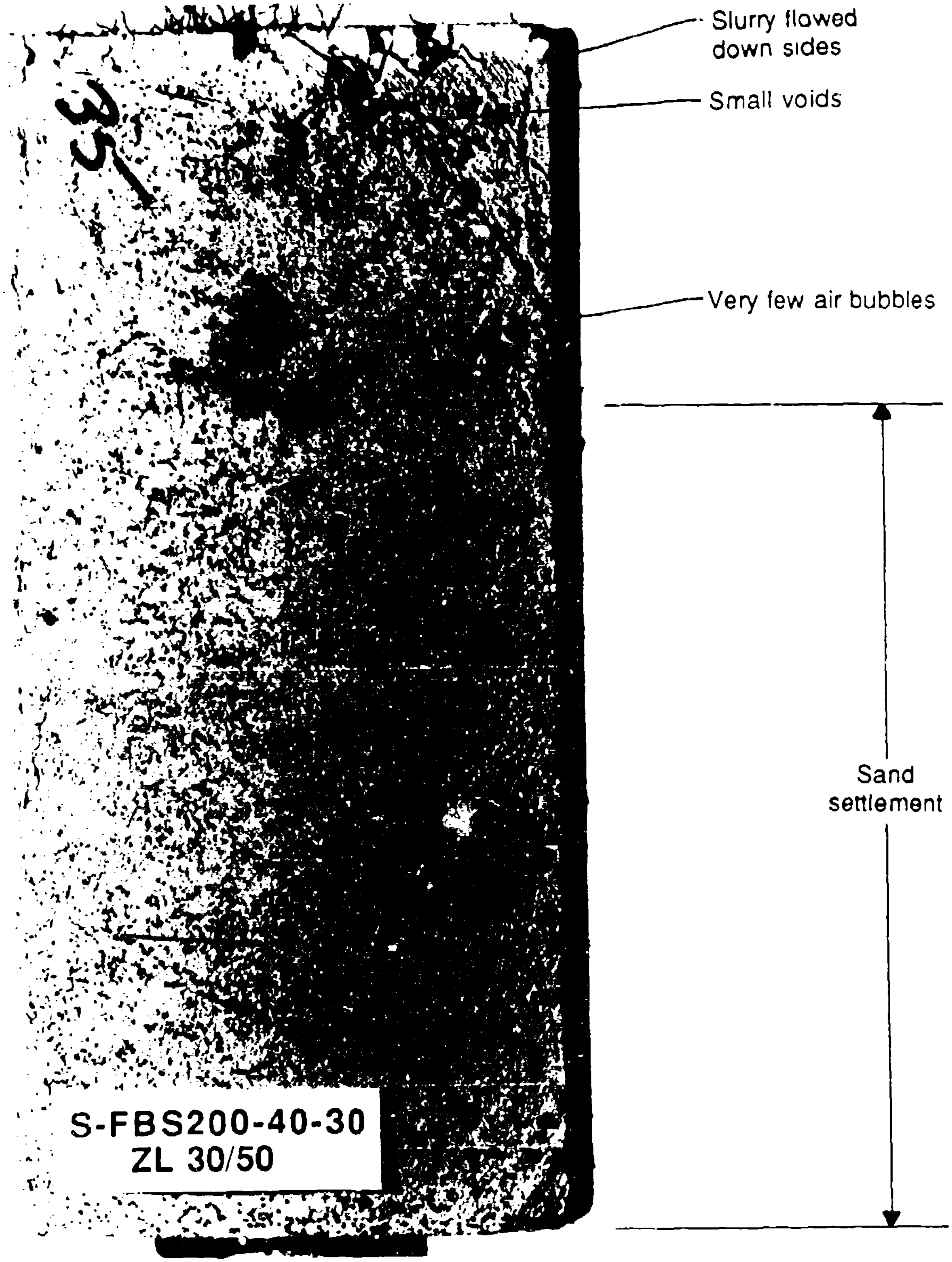


Figure A64. Fine blasting sand (200%) in fluid mix -- ZL 30/50 fibers, much vibration.

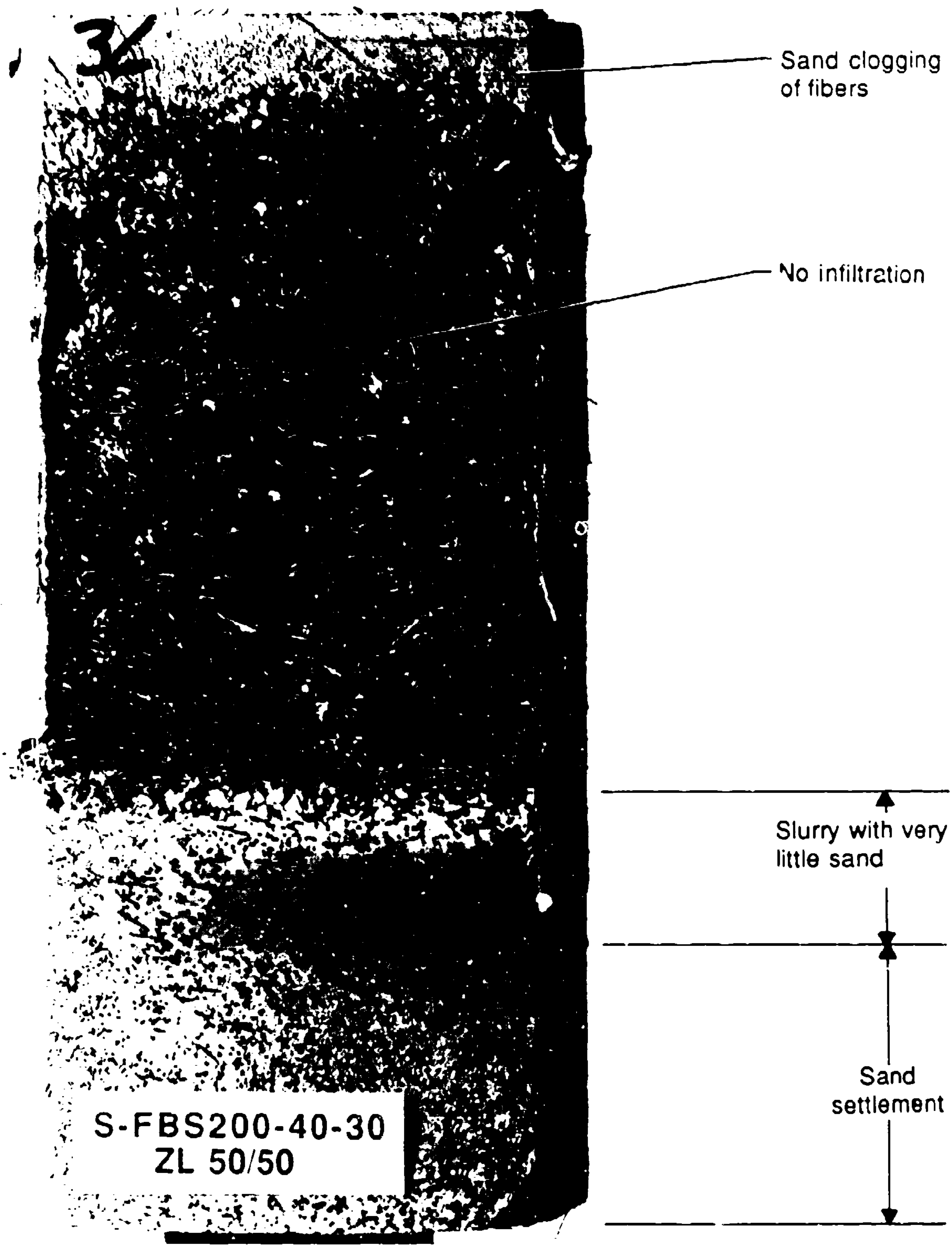


Figure A65. Fine blasting sand (200%) in fluid mix -- ZL 50/50 fibers.

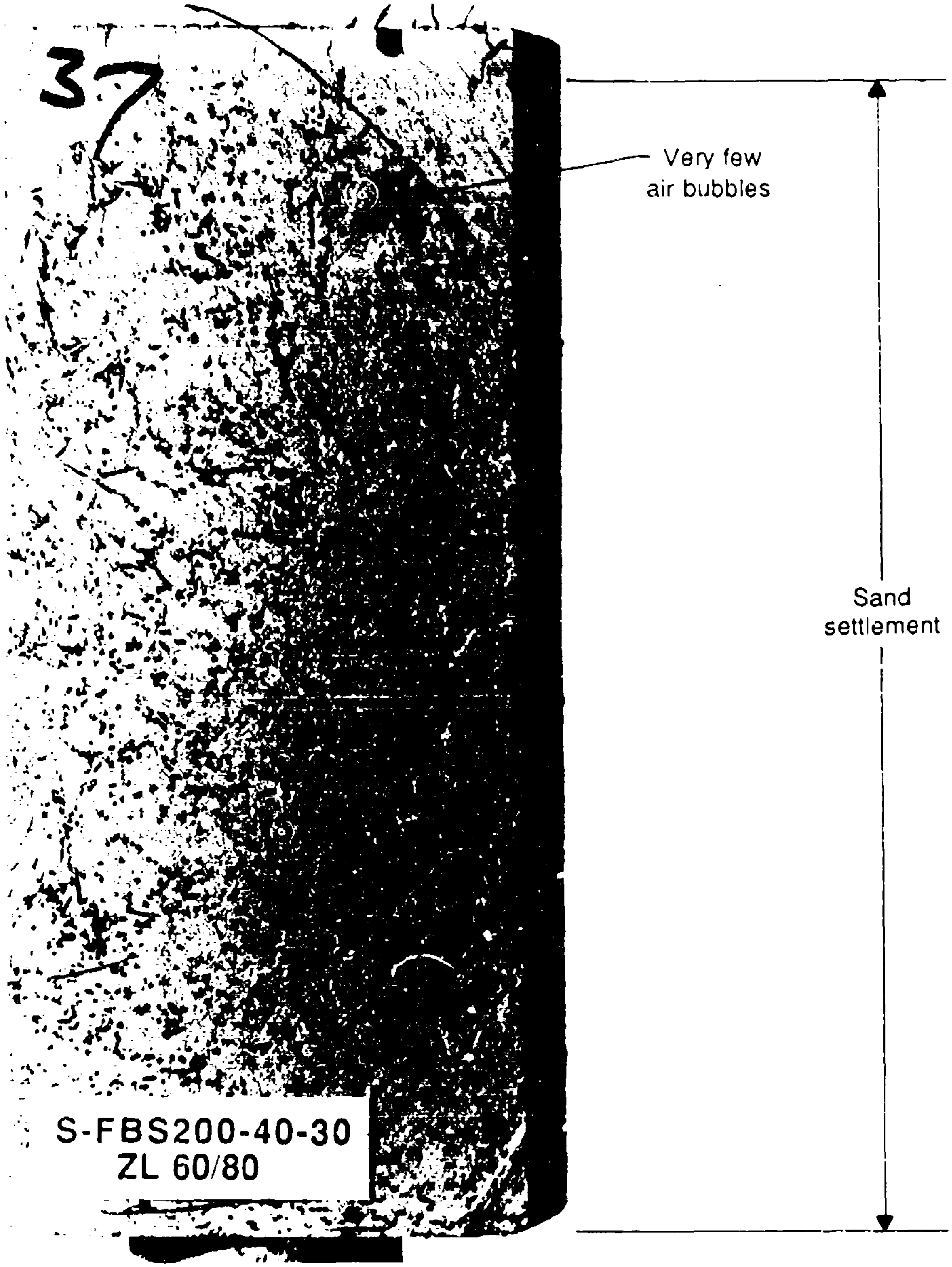


Figure A66. Fine blasting sand (200%) in fluid mix -- ZL 60/80 fibers.

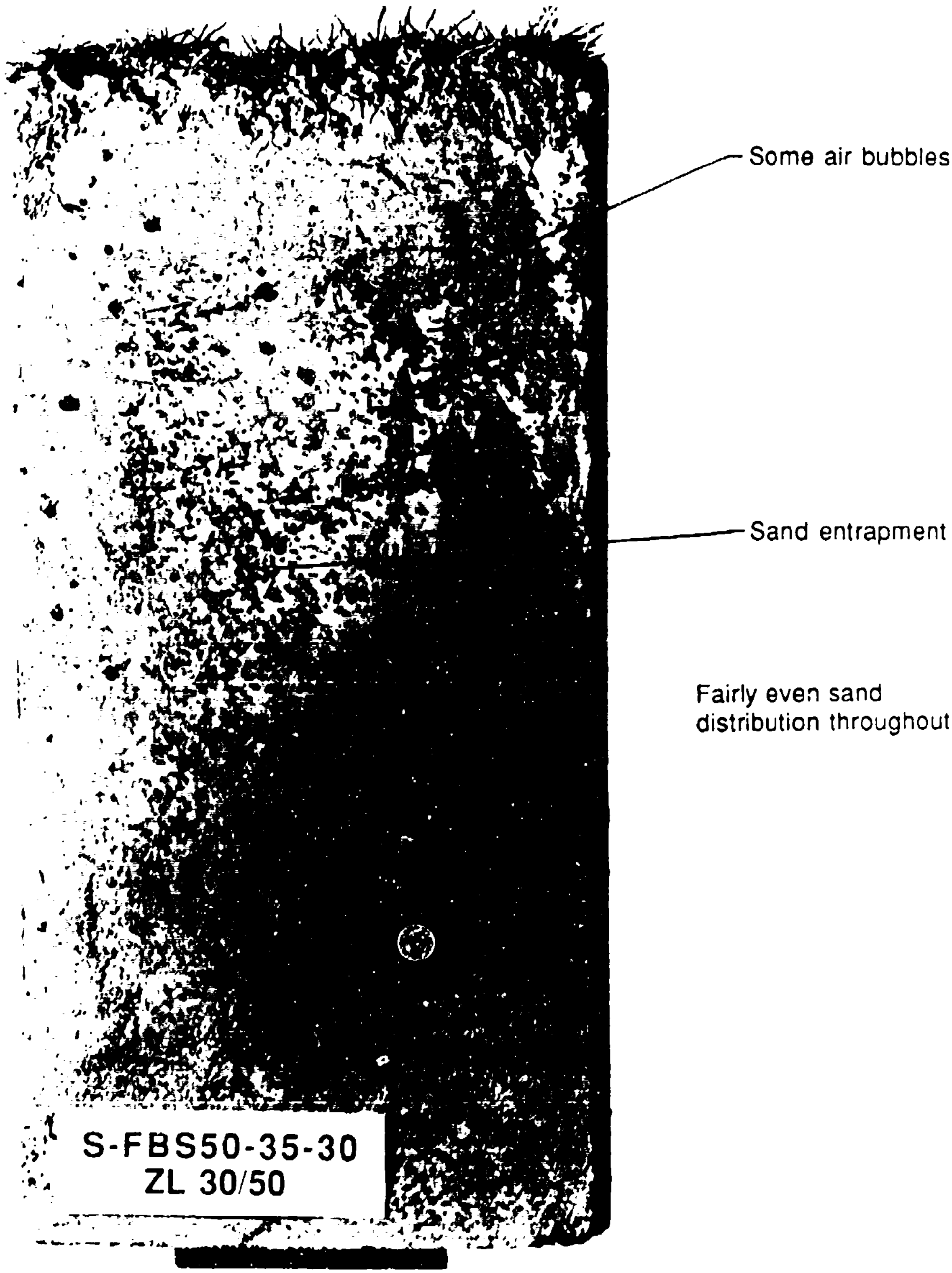


Figure A67. Fine blasting sand (50%) in moderately viscous mix -- ZL 30/50 fibers.

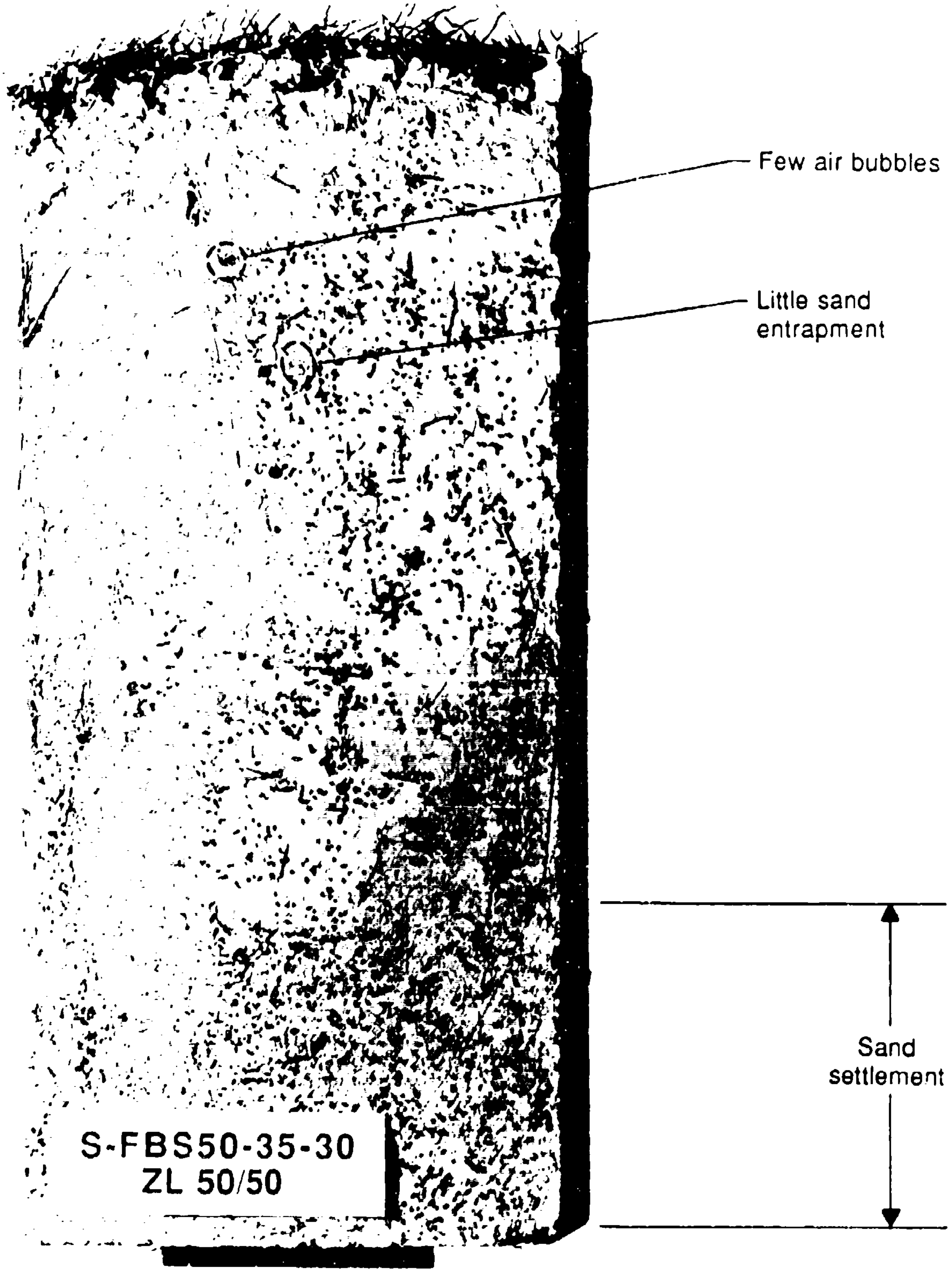


Figure A68. Fine blasting sand (50%) in moder. ;y viscous mix -- ZL 50/50 fibers.

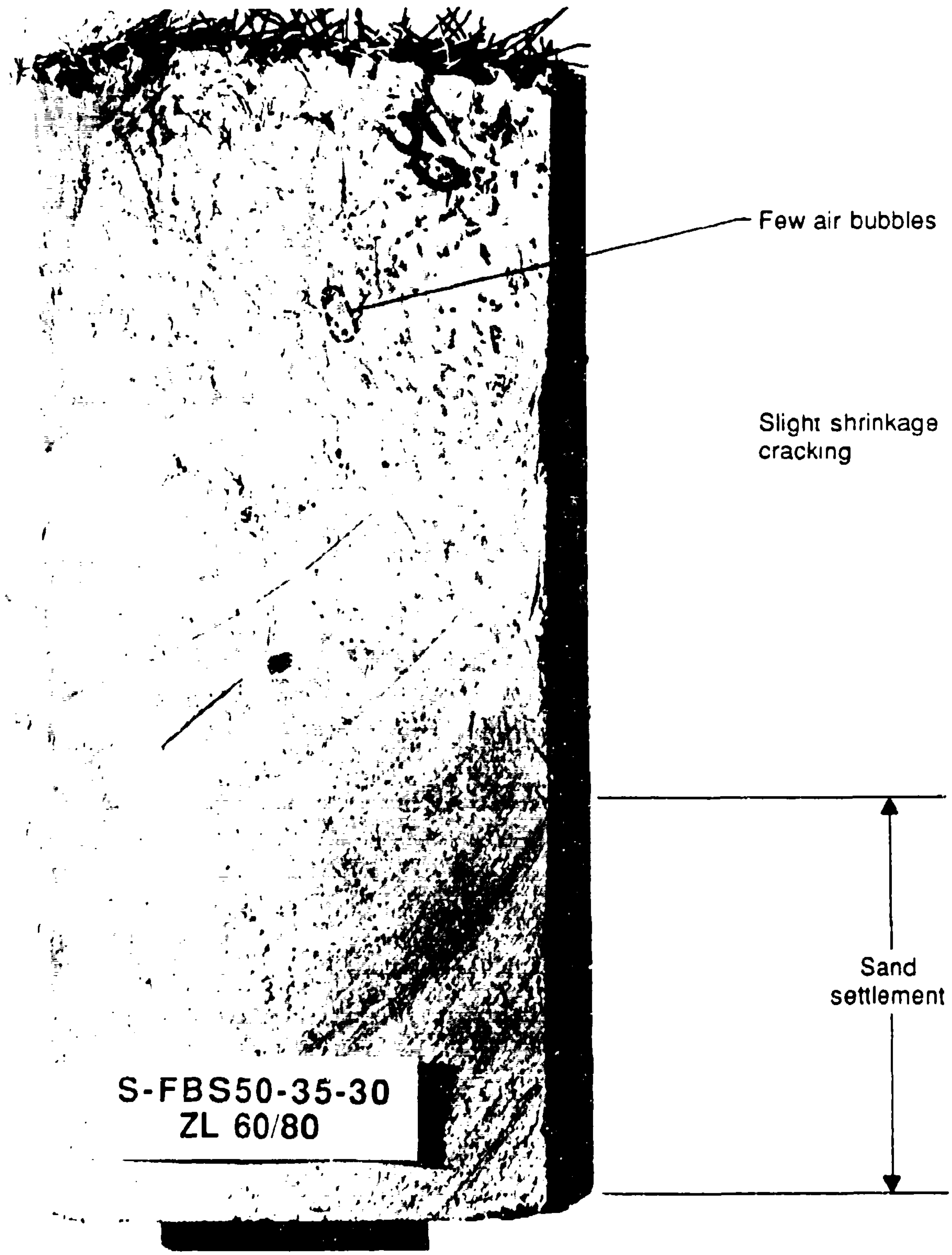


Figure A69. Fine blasting sand (50%) in moderately viscous mix -- ZL 60/80 fibers.

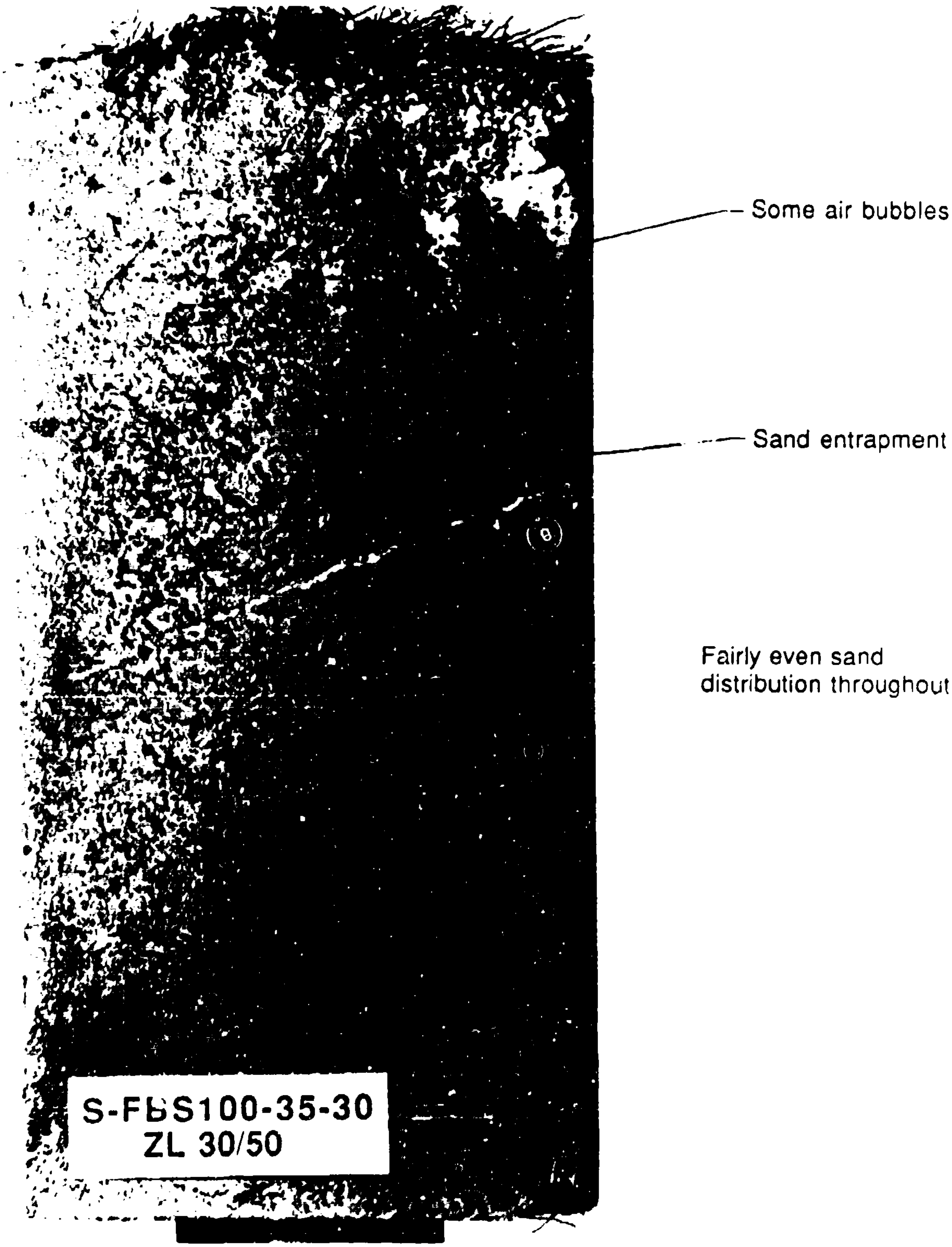


Figure A70. Fine blasting sand (100%) in moderately viscous mix -- ZL 30/50 fibers.

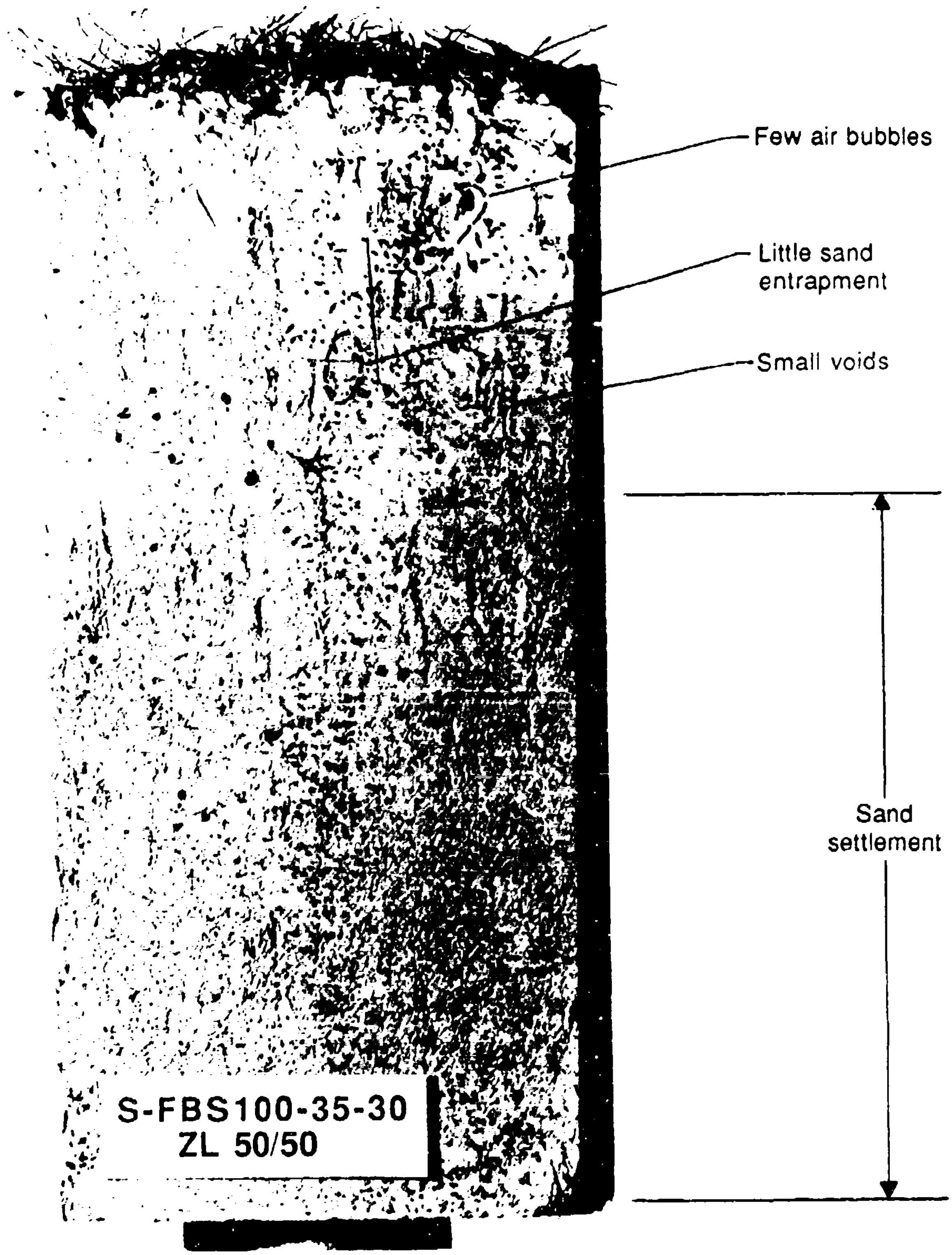


Figure A71. Fine blasting sand (100%) in moderately viscous mix -- ZL 50/50 fibers.

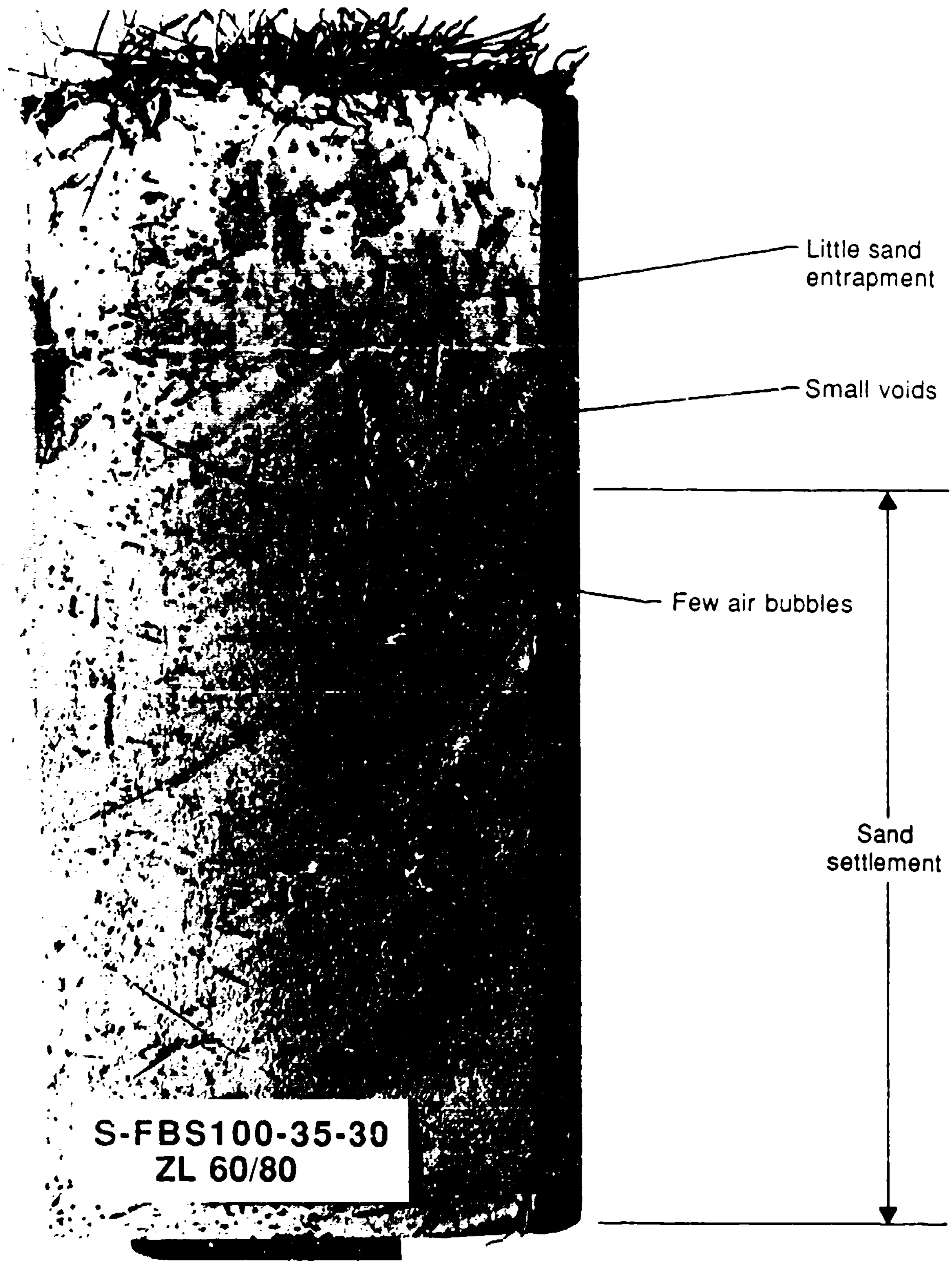


Figure A72. Fine blasting sand (100%) in moderately viscous mix -- ZL 60/80 fibers.

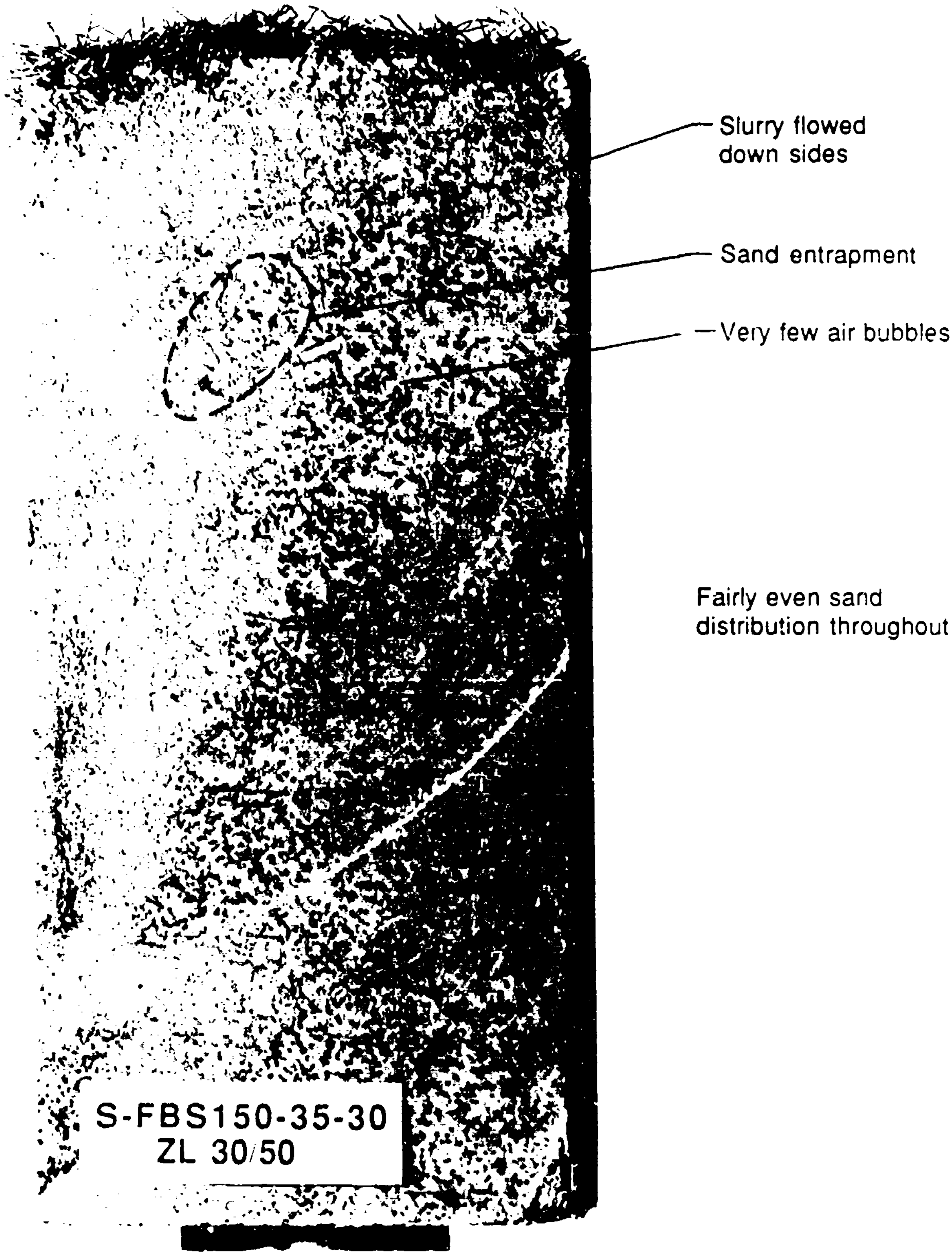


Figure A73. Fine blasting sand (150%) in moderately viscous mix -- ZL 30/50 fibers, moderate vibration.

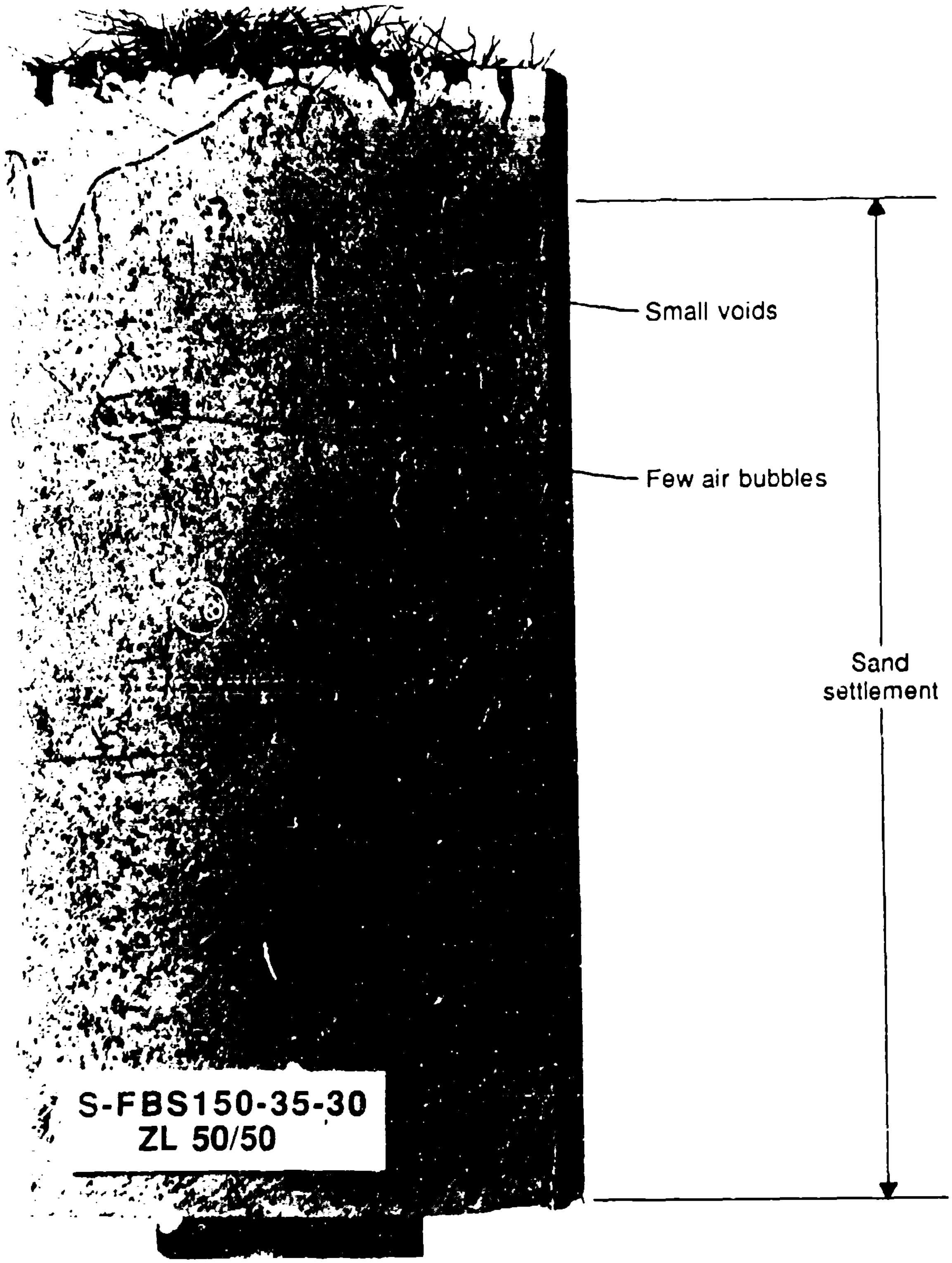


Figure A74. Fine blasting sand (150%) in moderately viscous mix -- ZL 50/50 fibers.

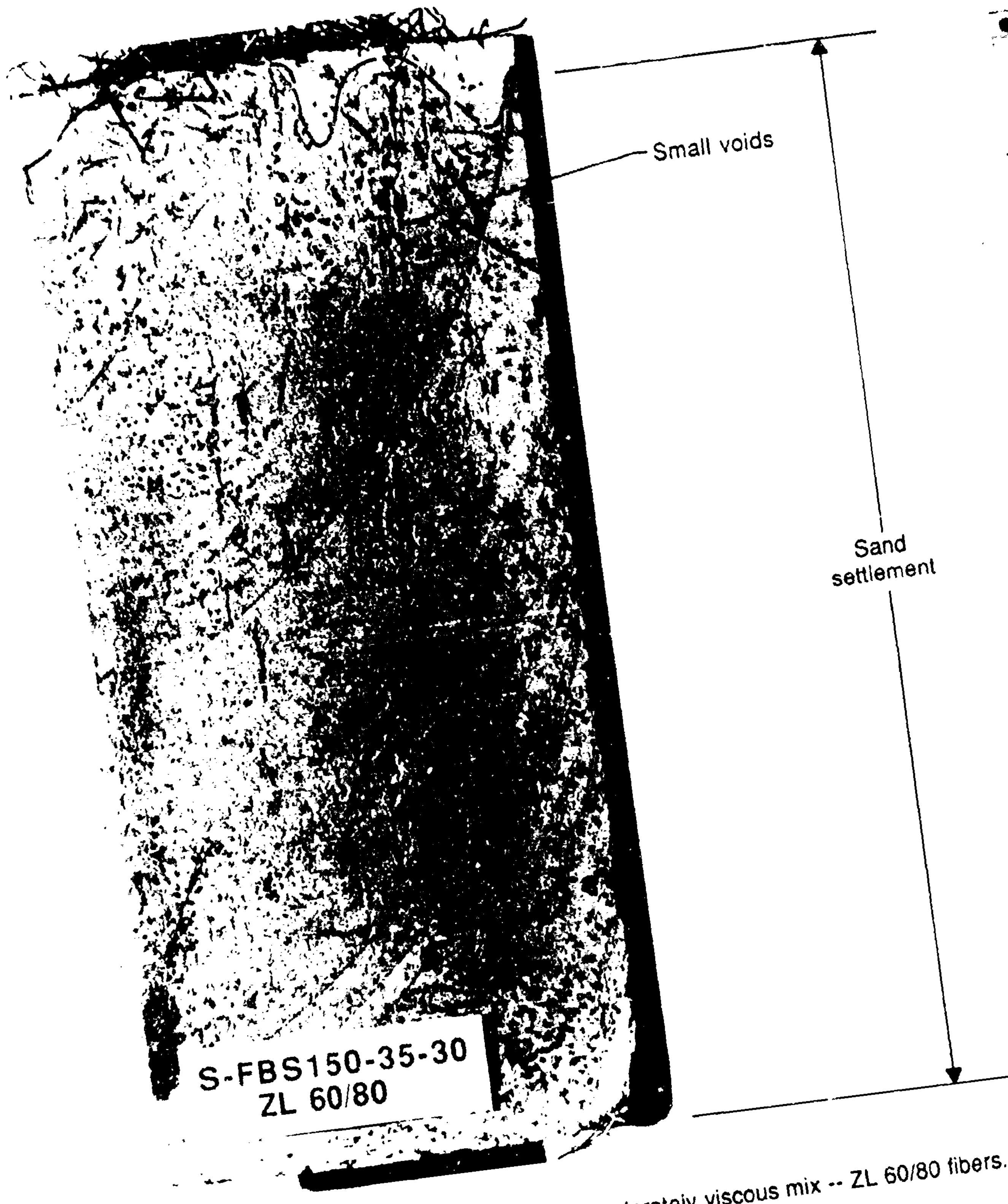


Figure A75. Fine blasting sand (150%) in moderately viscous mix -- ZL 60/80 fibers.

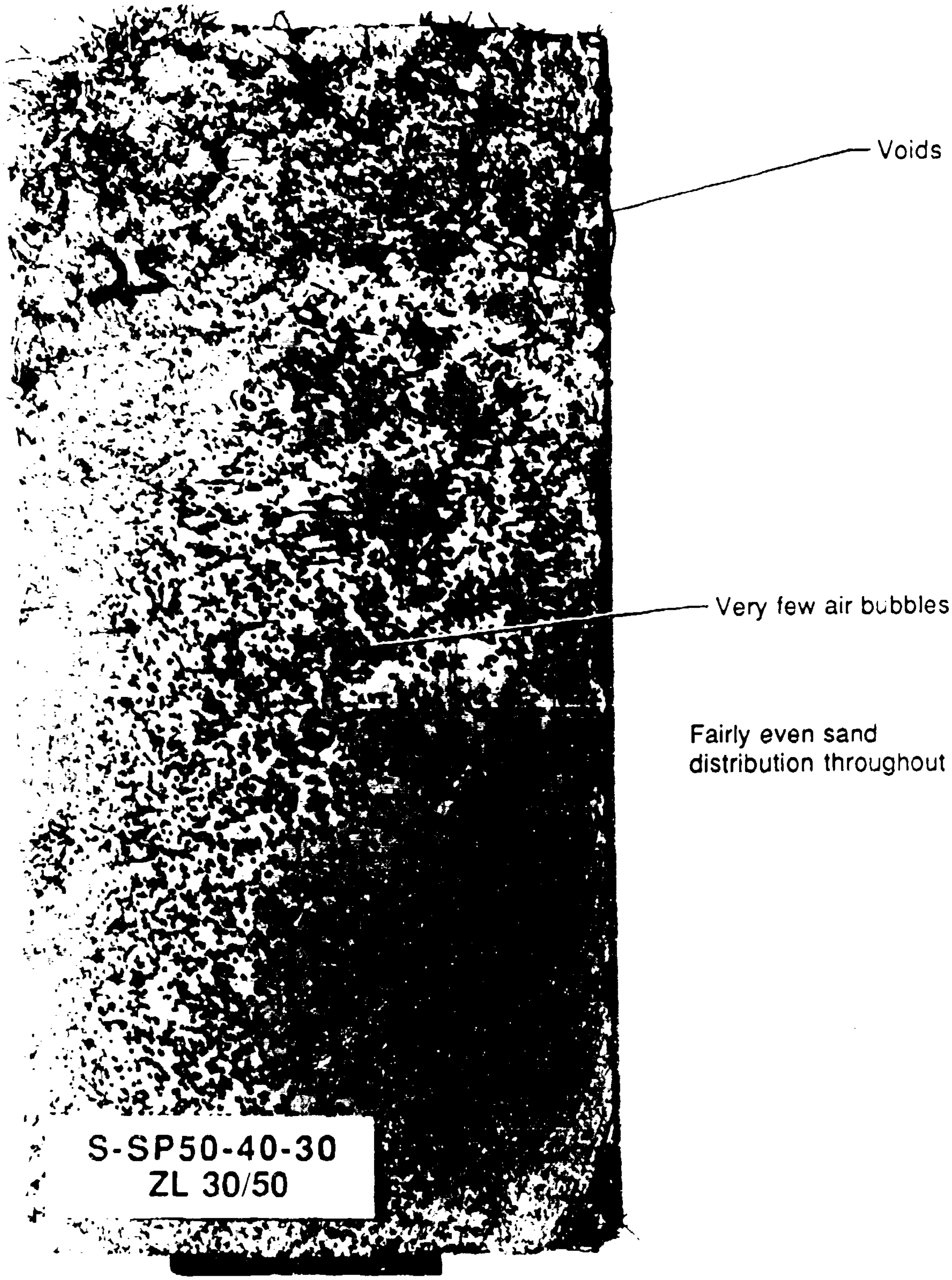


Figure A76. Washed plaster sand (50%) in fluid mix -- ZL 30/50 fibers.

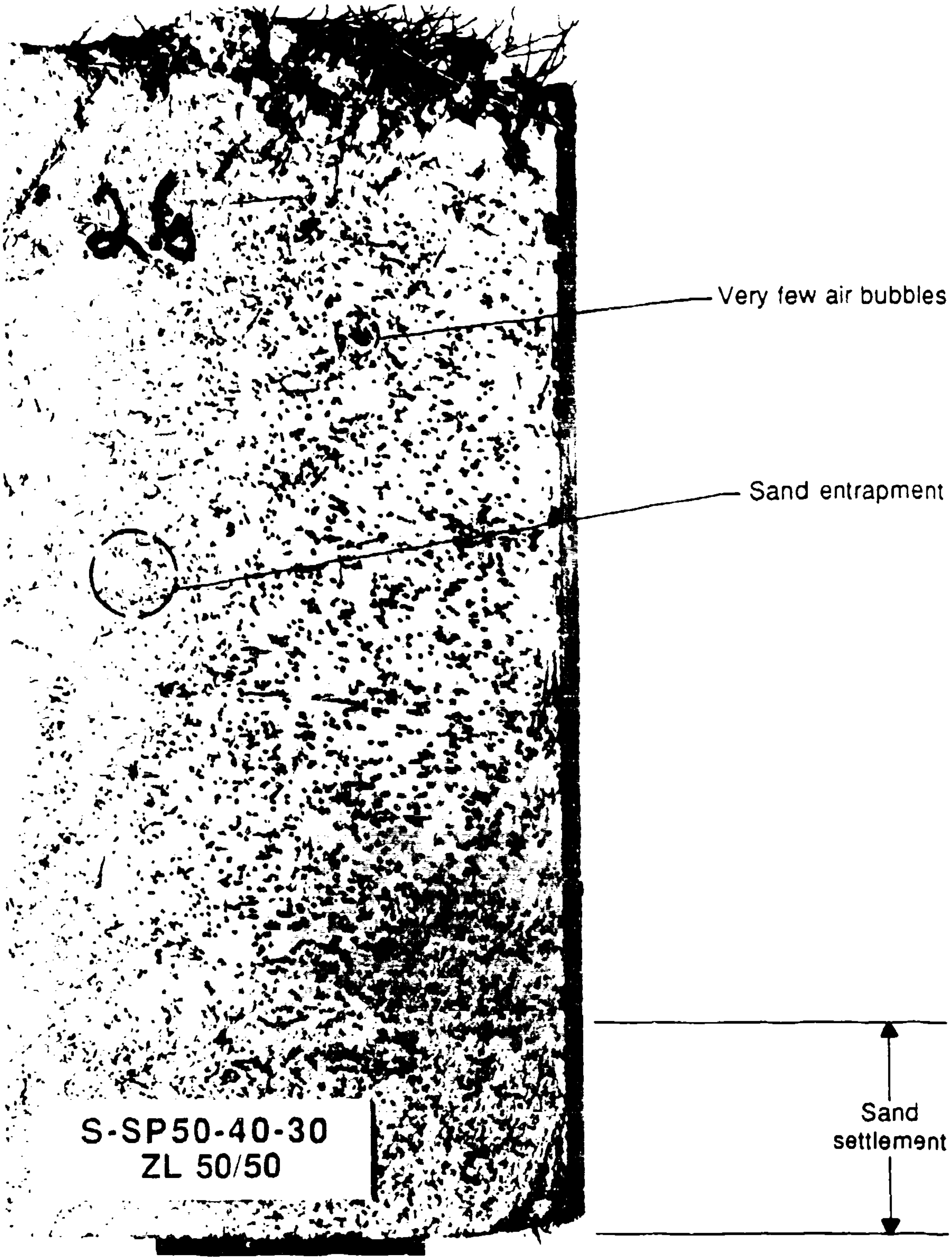


Figure A77. Washed plaster sand (50%) in fluid mix -- ZL 50/50 fibers.

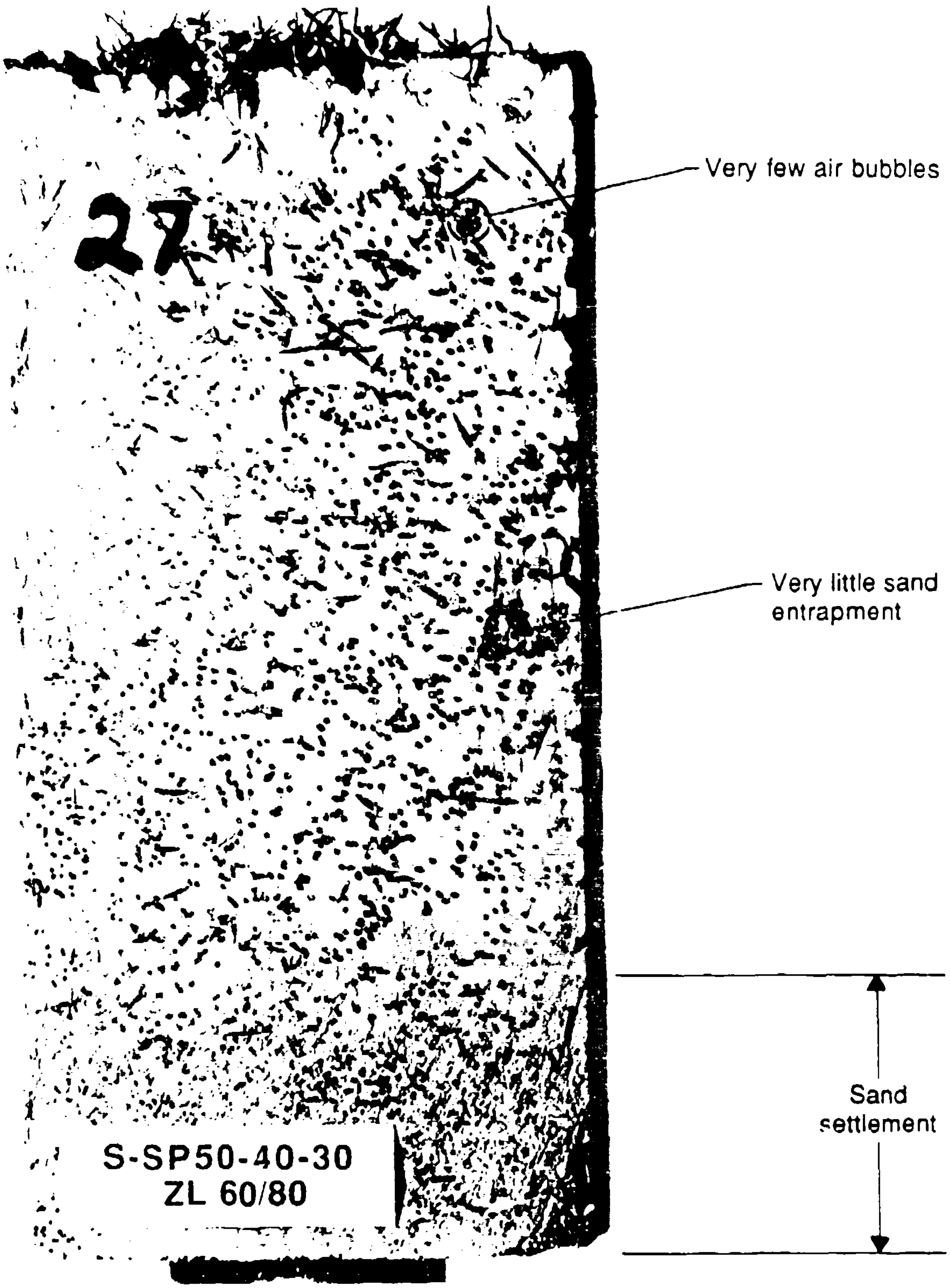


Figure A78. Washed plaster sand (50%) in fluid mix -- ZL 60/80 fibers.

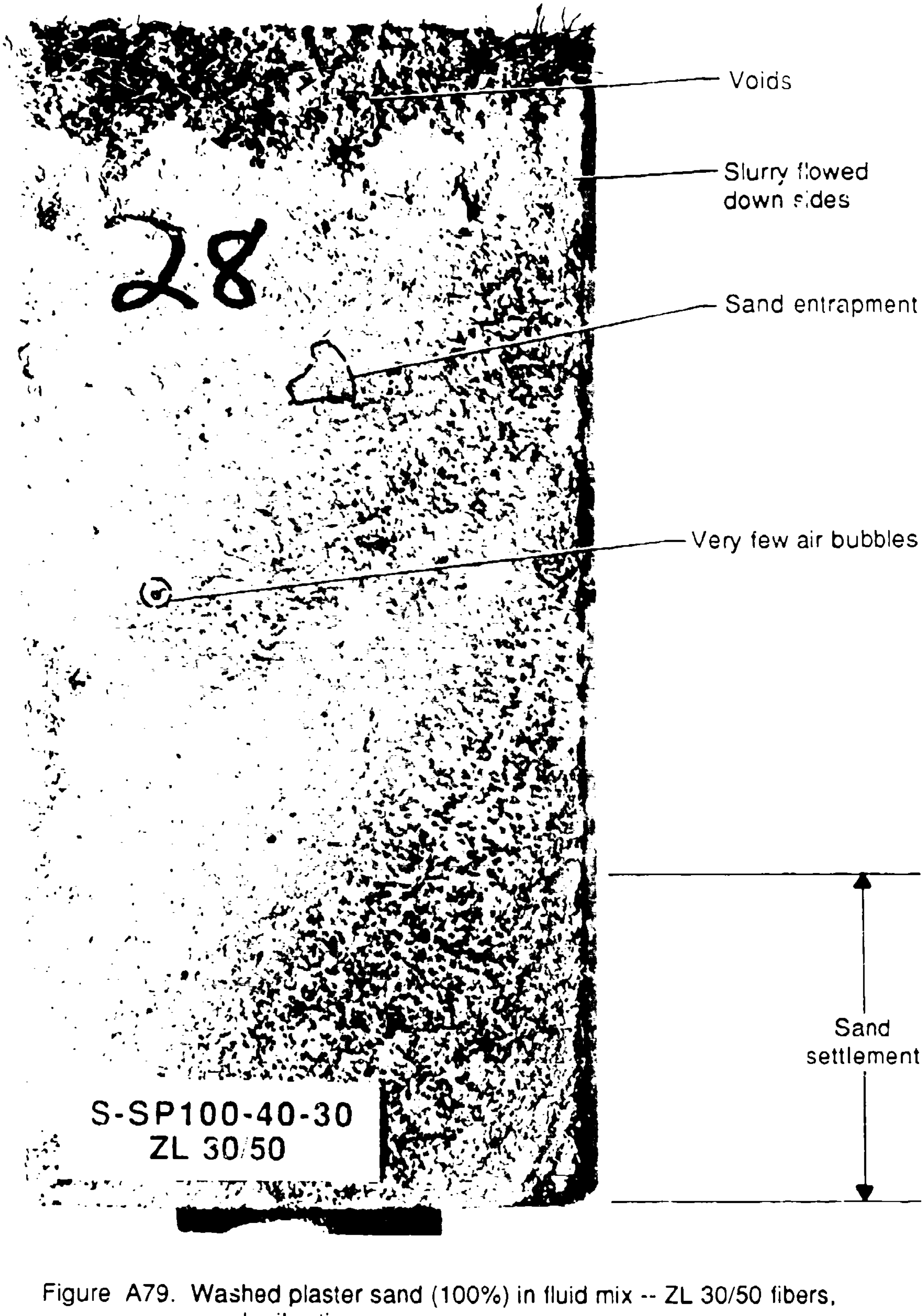


Figure A79. Washed plaster sand (100%) in fluid mix -- ZL 30/50 fibers, much vibration.

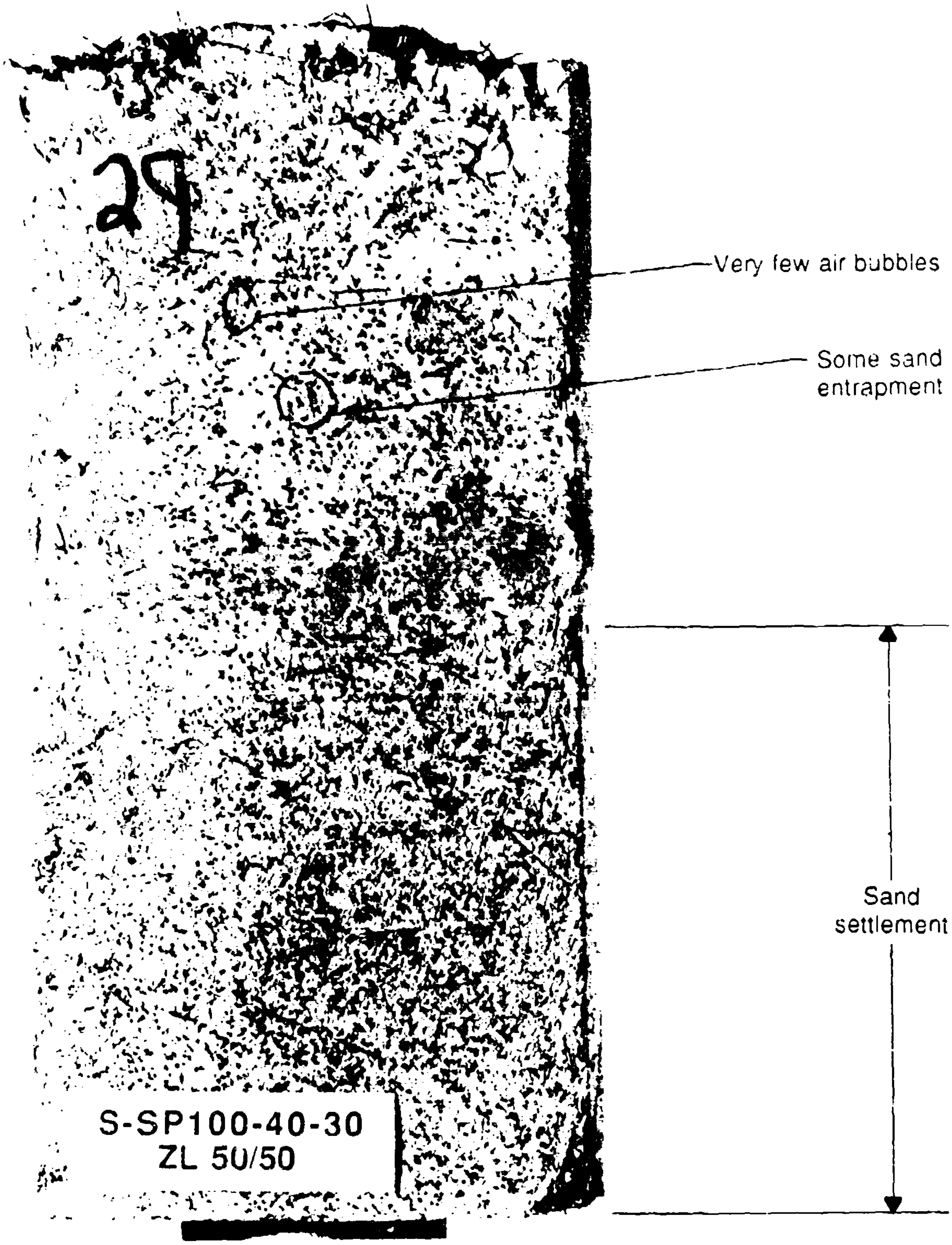


Figure A80. Washed plaster sand (100%) in fluid mix -- ZL 50/50 fibers.

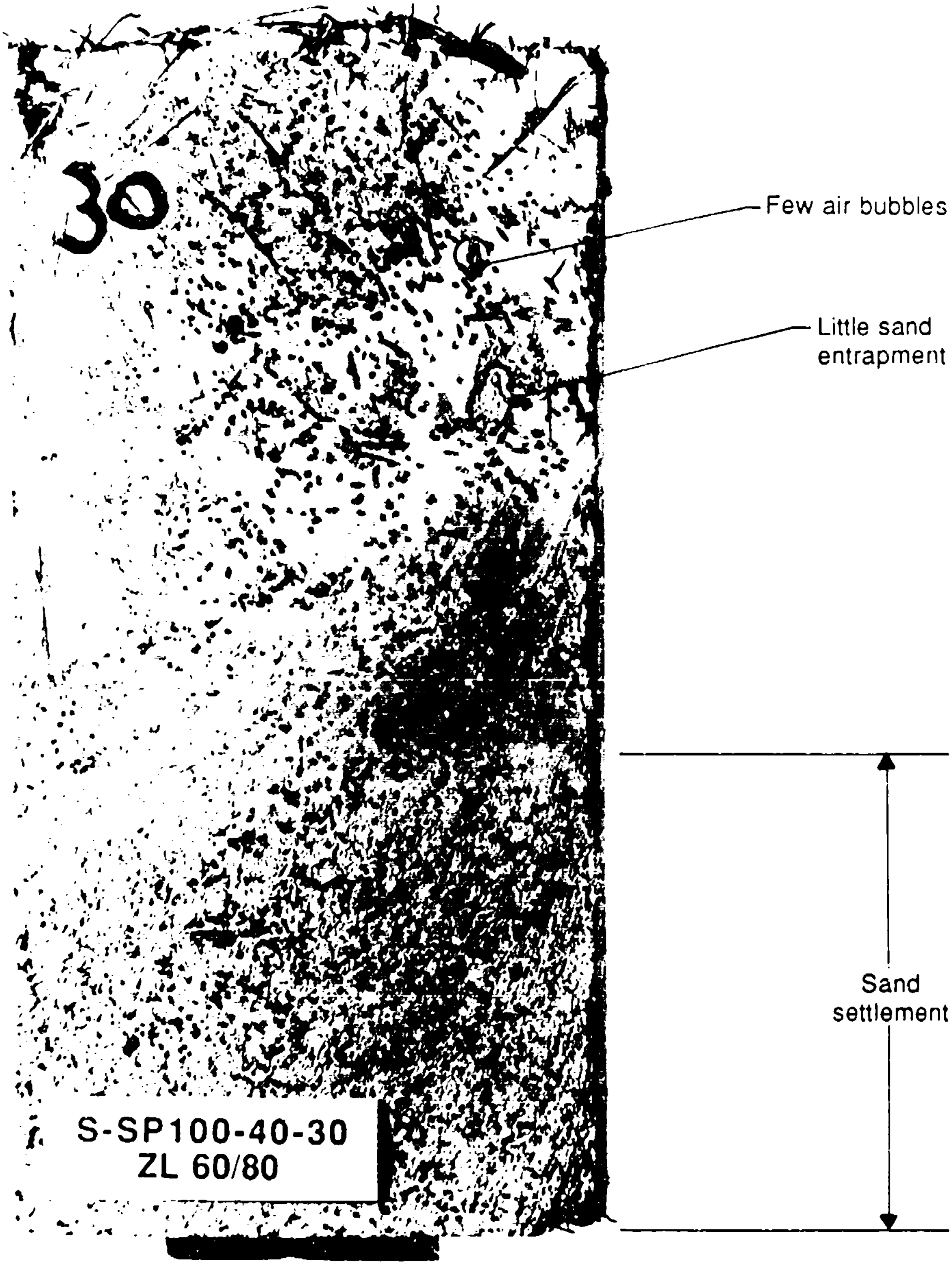


Figure A81. Washed plaster sand (100%) in fluid mix -- ZL 60/80 fibers.

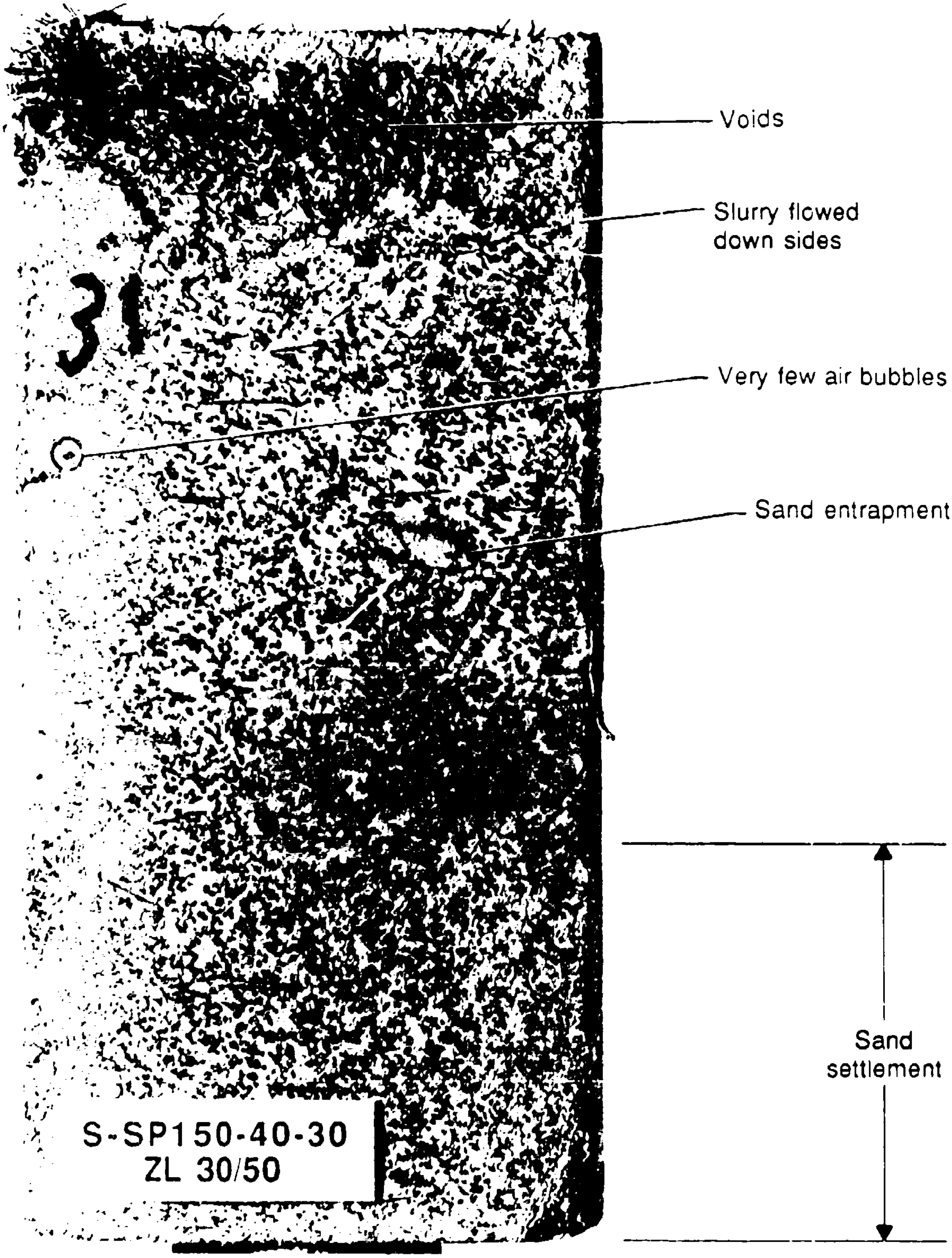


Figure A82. Washed plaster sand (150%) in fluid mix -- ZL 30/50 fibers, much vibration.

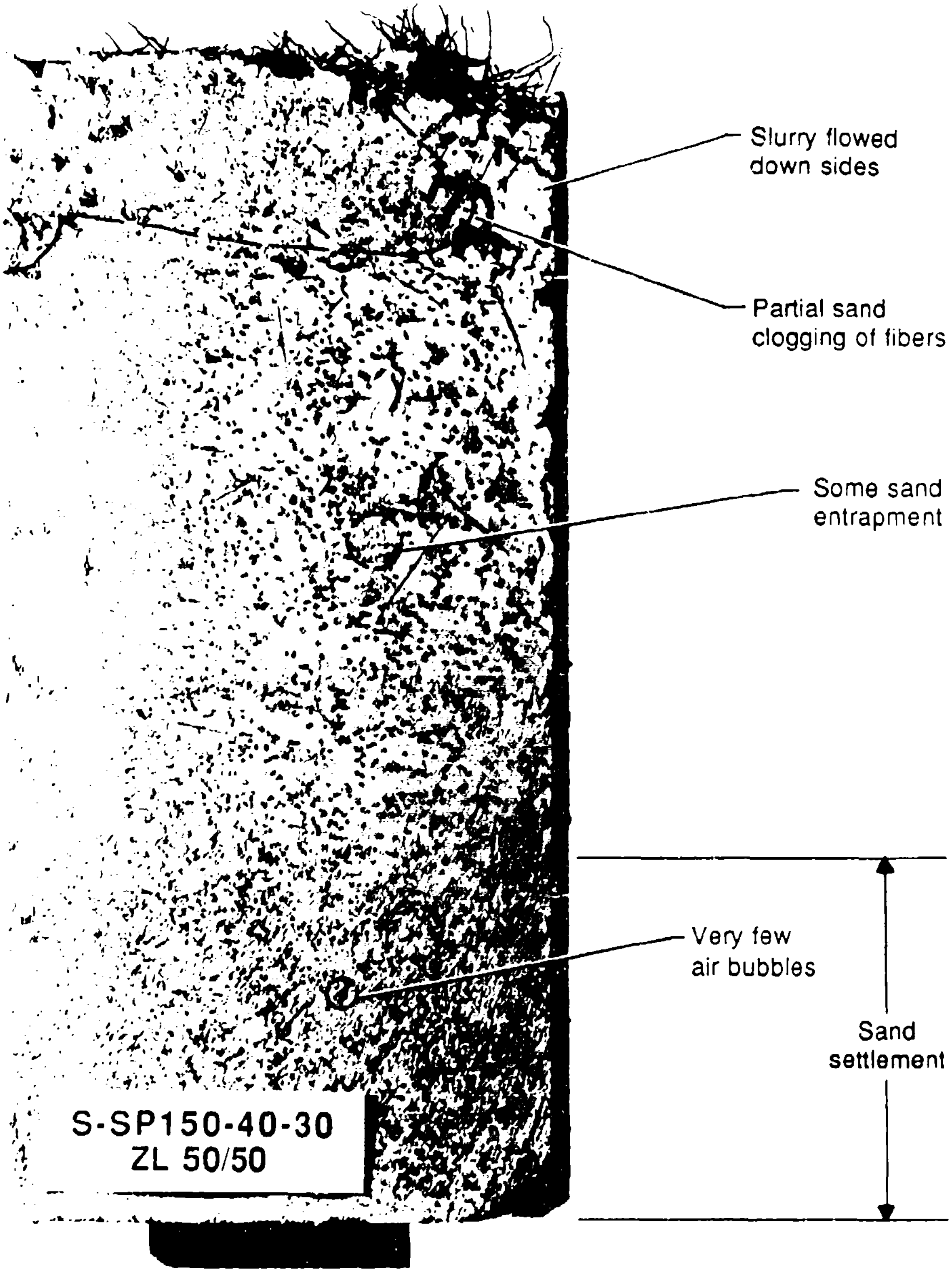


Figure A83. Washed plaster sand (150%) in fluid mix -- ZL 50/50 fibers, moderate vibration.

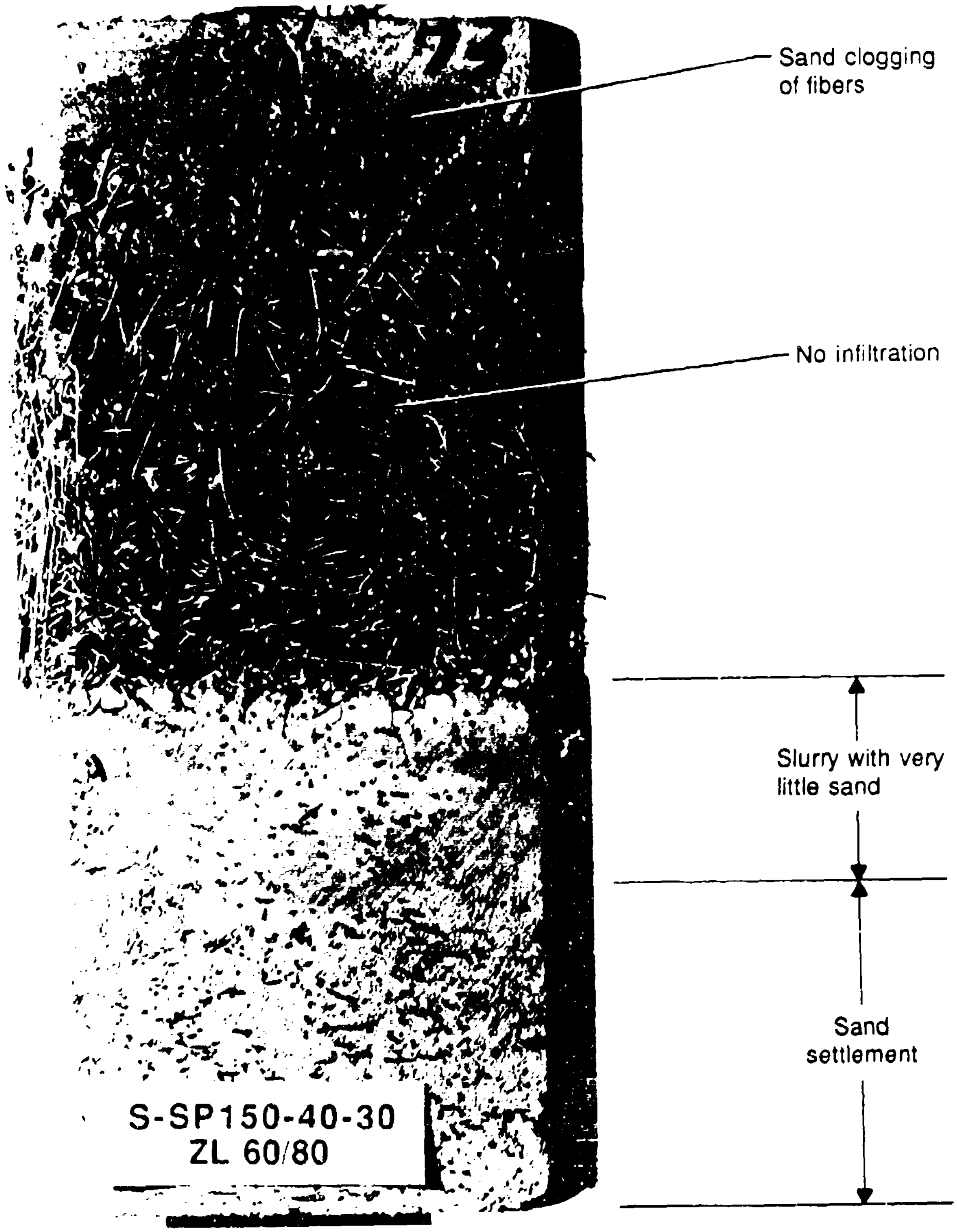


Figure A84. Washed plaster sand (150%) in fluid mix -- ZL 60/80 fibers.

APPENDIX B
SELECTED SIFCON STUDY

This appendix contains the mix designs (Table B1), compression test stress versus strain plots (Figures B1 through B20), and the results of a SIFCON material costs study (Table B2) for the selected SIFCON phase of this program.

TABLE B1. Selected SIFCON study mix designs.

Constants:	Fiber types:	Dramix ZL 30/50, ZL 50/50, ZL 60/80
Variables:	Sand/cement:	50 to 150 percent
	Water/cement + fly ash:	0.35 to .4233

Mix weights and measures

Mix identification code	Cement, lb	Fly ash, lb	Water, lb	Microsilica, lb	Superplasticizer, cm^3	Sand, lb	Aggregate, lb	Fiber, lb
S-5M150-15-42-0	127.00		53.76	19.00	1900	190.50	0.00	
Aggr. & ZL 60/80	(23.79)		(10.07)	(3.56)	(356)	(35.68)	13.64	19.34
S-5M100-10-37-0	153.00		56.15	15.30	1740	153.00	0.00	
Aggr. & ZL 60/80	(29.91)		(10.98)	(2.99)	(340)	(29.91)	10.75	20.84
S-5M150-37-10	130.00	14.44	53.63		1710	195.01	0.00	
Aggr. & ZL 60/80	(23.02)	(2.56)	(9.50)		(303)	(34.53)	12.28	18.25
S-3M100-10-38-0[a]	153.00		58.08	15.30	1740	153.00	0.00	
Aggr. & ZL 60/80	(29.38)		(11.15)	(2.94)	(334)	(29.38)	12.66	17.98
S-5M50-15-35-10	164.00	18.22	63.78	24.60	2235[b]	82.00	0.00	
Aggr. & ZL 60/80	(30.37)	(3.37)	(11.81)	(4.56)	(414)	(15.18)	13.61	18.87

Note : Numbers in parentheses are calculated values.

[a] All mixes contain 50-mesh sand except S-3M100-10-83-0 which contains 30-mesh.

[b] All mixes that contain microsilica contain EMS 960 except for this which contains Force 10,000.

Mix proportions

Mix identification code	Cement (C/C+FA), %	Fly ash (FA/C+FA), %	Water (W/C+FA)	Microsilica (M/C), %	Superplasticizer, oz/100wt	Sand (S/C), %	Aggregate (A/C), %	Fiber, %by vol.
S-5M150-15-42-0	100	0	0.4233	14.96	44.01	150	0.00	11, 8.5, 6
Aggr. & ZL 60/80	100	0	0.4233	14.96	44.01	150	57.34	6.06
S-5M100-10-37-0	100	0	0.3670	10.00	34.96	100	0.00	11, 8.5, 6
Aggr. & ZL 60/80	100	0	0.3670	10.00	34.96	100	35.94	6.62
S-5M150-37-10	90	10	0.3713	0.00	40.04	150	0.00	11, 8.5, 6
Aggr. & ZL 60/80	90	10	0.3713	0.00	40.04	150	53.35	6.08
S-3M100-10-38-0	100	0	0.3796	10.00	34.96	100	0.00	11, 8.5, 6
Aggr. & ZL 60/80	100	0	0.3796	10.00	34.96	100	43.77	5.68
S-5M50-15-35-10	90	10	0.3500	15.00	36.55	50	0.00	11, 8.5, 6
Aggr. & ZL 60/80	90	10	0.3500	15.00	36.55	50	44.81	6.23

TABLE B2. SIFCON material costs.

Unit costs

Material	Units	Cost
Cement	$/lb	0.0530
Fly ash	$/lb	0.0225
Sand	$/lb	0.0100
Aggregate	$/lb	0.0060
Microsilica (EMS 960)	$/lb	0.0800
Superplasticizer	$/gal	7.5000
Fiber	$/lb	0.4800

Efficiency factor =

$$\frac{(SIF - Slu)/Slu}{Fib}$$

Where : SIF = SIFCON strength
Slu = Slurry strength
Fib = Steel fiber percent

Material costs for selected SIFCON mixes

S-5M150-15-42-0

Material	Material costs. $/cu yd				
	Slurry	ZL30/50 11%	ZL50/50 6%	ZL60/80 8.50%	Agg. & ZL60/80 6.06%
Cement	64.52	57.43	60.65	59.04	52.28
Sand	18.26	16.25	17.17	16.71	14.80
Aggregate					3.39
Microsilica (EMS 960)	14.57	12.97	13.70	13.33	11.81
Superplasticizer	36.09	32.12	33.93	33.02	29.24
Fiber		698.54	381.02	539.78	384.83
Total cost, $	133.45	817.31	506.46	661.89	496.36
Strength, lb/in^2	11,209	25,724	17,851	18,448	16,968
Strength/dollar, lb/in^2/$	84	31	35	28	34
Efficiency factor		11.8	9.9	7.6	8.5
Same mix omitting the sand and aggregate					
Cement	110.66	98.48	104.02	101.25	101.25
Microsilica (EMS 960)	24.99	22.24	23.49	22.86	22.86
Superplasticizer	61.89	55.09	58.18	56.63	56.63
Fiber	0.00	698.54	381.02	539.78	539.78
Total cost, $	197.54	874.35	566.71	720.53	720.53
Savings, %	32.44	6.52	10.63	8.14	31.11

TABLE B2. Continued.

S-5M100-10-37-0

Material	Material costs, $/cu yd				
	Slurry 0%	ZL30/50 11%	ZL50/50 6%	ZL60/80 8.50%	Agg. & ZL60/80 6.06%
Cement	80.21	71.38	75.39	73.39	66.62
Sand	15.13	13.47	14.23	13.85	12.57
Aggregate					2.71
Microsilica (EMS 960)	12.11	10.77	11.38	11.08	10.06
Superplasticizer	34.10	30.35	32.05	31.20	28.32
Fiber		698.54	381.02	539.78	420.40
Total cost, $	141.54	824.52	514.07	669.30	540.68
Strength, lb/in^2	10,563	22,617	16,062	17,833	19,000
Strength/dollar, lb/in^2/$	75	27	31	27	35
Efficiency factor		10.4	8.7	8.1	12.1
Same mix omitting the sand and aggregate					
Cement	122.54	109.06	115.19	112.12	112.12
Microsilica (EMS 960)	18.50	16.46	17.39	16.92	16.92
Superplasticizer	52.10	46.37	48.97	47.67	47.67
Fiber	0.00	698.54	381.02	539.78	539.78
Total cost, $	193.13	870.43	562.57	716.50	716.50
Savings, %	26.71	5.27	8.62	6.59	24.54

S-5M150-37-10

Cement	65.89	58.64	61.93	60.29	53.74
Fly ash	3.11	2.77	2.92	2.84	2.54
Sand	18.65	16.60	17.53	17.06	15.21
Aggregate					3.25
Superplasticizer	32.41	28.84	30.46	29.65	26.43
Fiber		698.54	381.02	539.78	386.10
Total cost, $	120.05	805.39	493.87	649.63	487.27
Strength, lb/in^2	7,220	19,033	13,076	14,070	12,783
Strength/dollar, lb/in^2/$	60	24	26	22	26
Efficiency factor		14.9	13.5	11.2	12.7
Same mix omitting the sand and aggregate					
Cement	114.73	102.11	107.84	104.97	104.97
Fly ash	5.41	4.82	5.09	4.95	4.95
Superplasticizer	56.43	50.22	53.04	51.63	51.63
Fiber	0.00	698.54	381.02	539.78	539.78
Total cost, $	176.56	855.69	546.99	701.34	701.34
Savings, %	32.01	5.88	9.71	7.37	30.52

TABLE B2. Concluded.

S-3M100-10-38-0

Material	Material costs, $/cu yd				
	Slurry 0%	ZL30/50 11%	ZL50/50 6%	ZL60/80 8.50%	Agg. & ZL60/80 6.06%
Cement	79.31	70.58	74.55	72.57	65.07
Sand	14.96	13.32	14.07	13.69	12.28
Aggregate					3.22
Microsilica (EMS 960)	11.97	10.65	11.25	10.95	9.82
Superplasticizer	33.72	30 01	31.69	30.85	27.67
Fiber		698.54	381.02	539.78	360.70
Total cost, $	139.96	823.11	512.59	667.85	478.77
Strength, lb/in^2	10,112	21,661	16,193	16,451	15,301
Strength/dollar, $lb/in^2/\$$	72	26	32	25	32
Efficiency factor		10.4	10.0	7.4	9.0
Same mix omitting the sand and aggregate					
Cement	120.46	107.21	113.23	110.22	110.22
Microsilica (EMS 960)	18.18	16.18	17.09	16.64	16.64
Superplasticizer	51.21	45.58	48.14	46.86	46.86
Fiber	0.00	698.54	381.02	539.78	539.78
Total cost, $	189.85	867.51	559.48	713.49	713.49
Savings, %	26.28	5.12	8.38	6.40	32.90

S-5M50-15-35-10

Material	Slurry 0%	ZL30/50 11%	ZL50/50 6%	ZL60/80 8.50%	Agg. & ZL60/80 6.06%
Cement	88.12	78.43	82.83	80.63	70.62
Fly ash	4.16	3.70	3.91	3.80	3.33
Sand	8.31	7.40	7.81	7.61	6.66
Aggregate					3.58
Microsilica (F 10,000)	19.95	17.76	18.75	18.26	15.99
Superplasticizer	44.90	39.96	42.21	41.09	35.99
Fiber		698.54	381.02	539.78	395.63
Total cost, $	165.44	845.79	536.54	691.17	531.80
Strength, lb/in^2	10,661	18,889	15,000	15,453	14,925
Strength/dollar, $lb/in^2/\$$	64	22	28	22	28
Efficiency factor		7.0	6.8	5.3	6.4
Same mix omitting the sand and aggregate					
Cement	108.76	96.80	102.23	99.51	99.51
Fly ash	5.13	4.57	4.82	4.69	4.69
Microsilica (F 10,000)	24.62	21.92	23.15	22.53	22.53
Superplasticizer	55.42	49.32	52.10	50.71	50.71
Fiber	0.00	698.54	381.02	539.78	539.78
Total cost, $	193.94	871.15	563.32	717.23	717.23
Savings, %	14.69	2.91	4.75	3.63	25.85

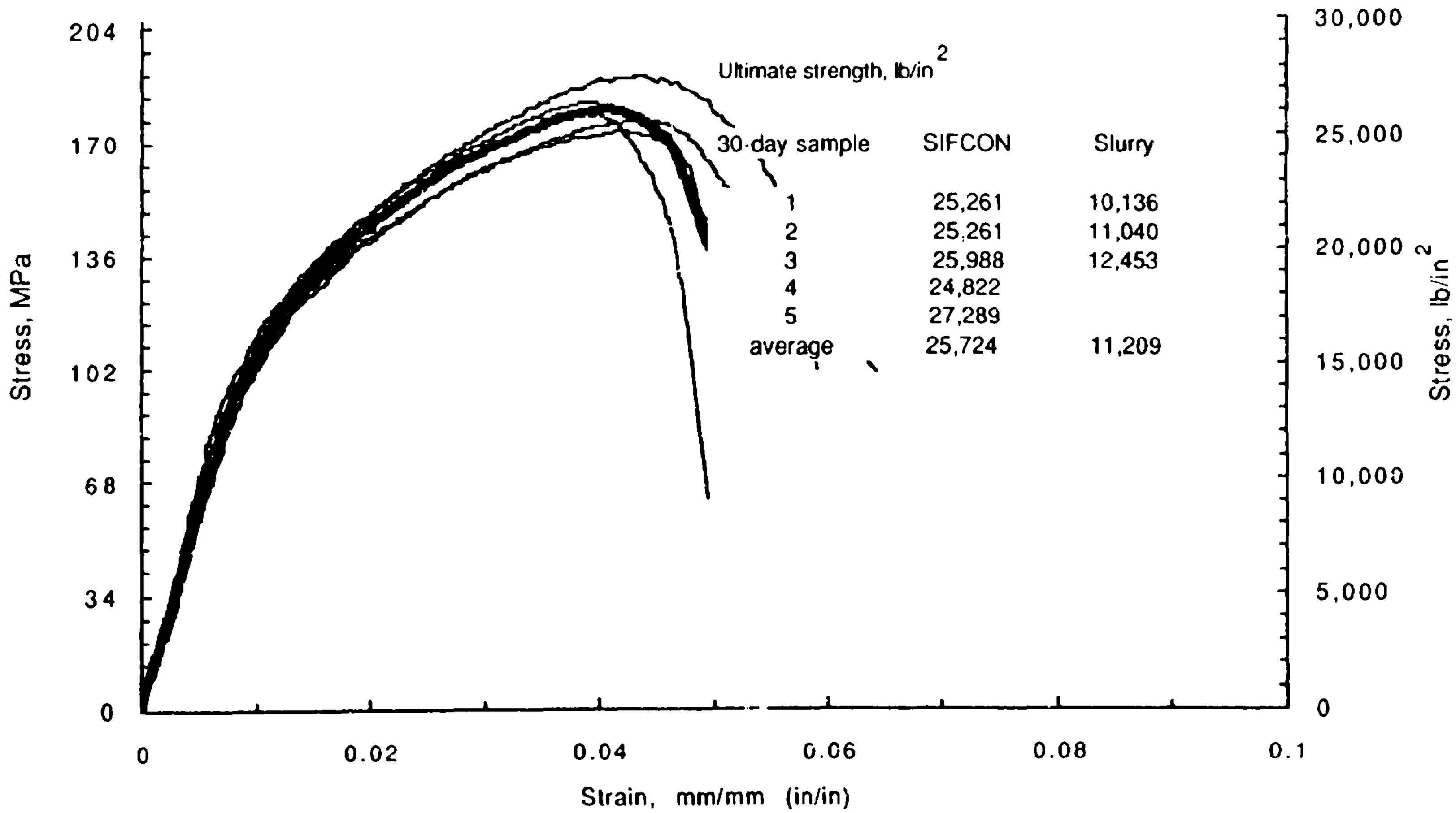


Figure B1. S-5M150-15-42-0 (ZL 30/50) -- compression.

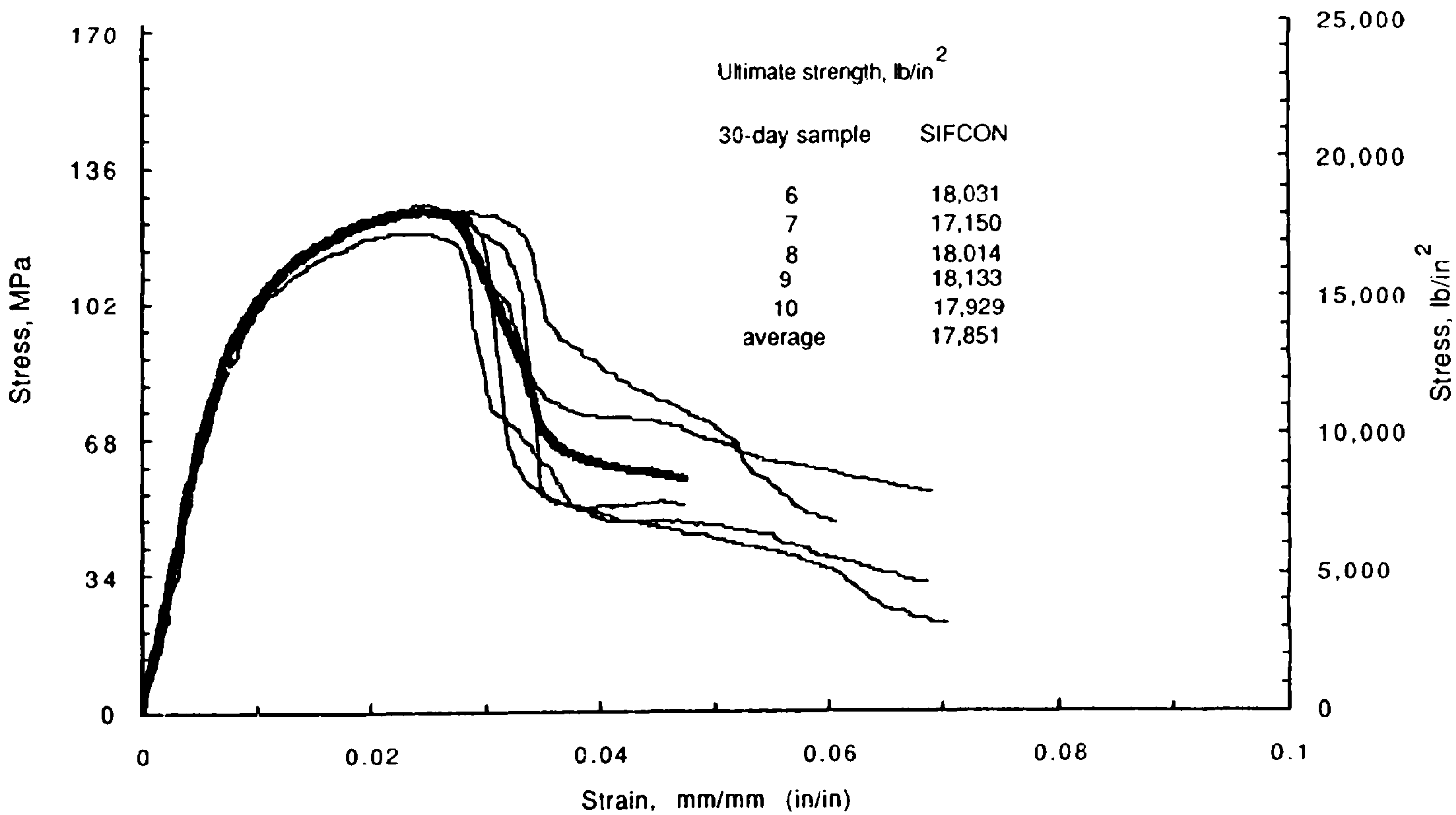


Figure B2. S-5M150-15-42-0 (ZL 50/50) -- compression.

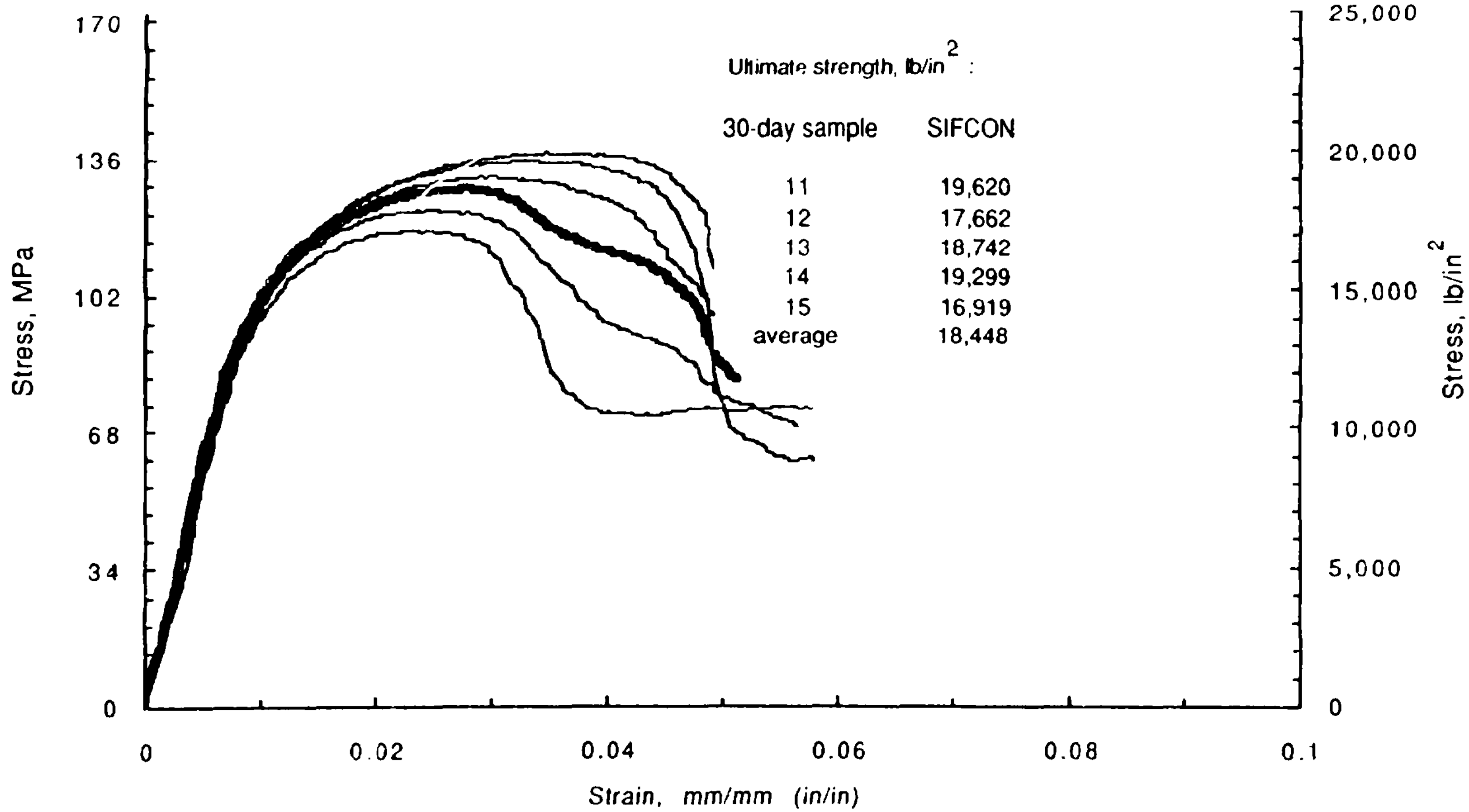


Figure B3. S-5M150-15-42-0 (ZL 60/80) -- compression.

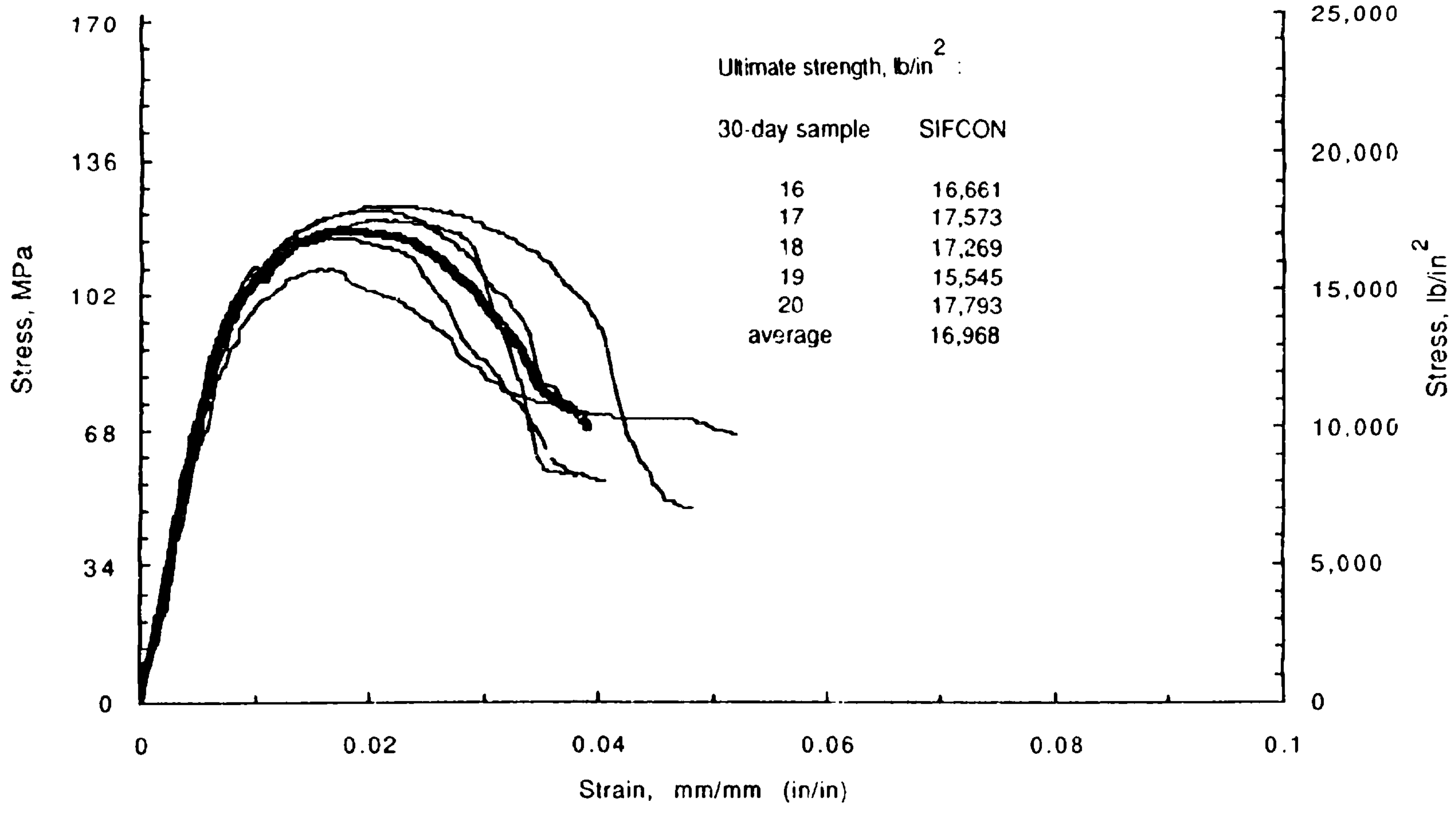


Figure B4. S-5M150-15-42-0 (aggregate and ZL 60/80) -- compression.

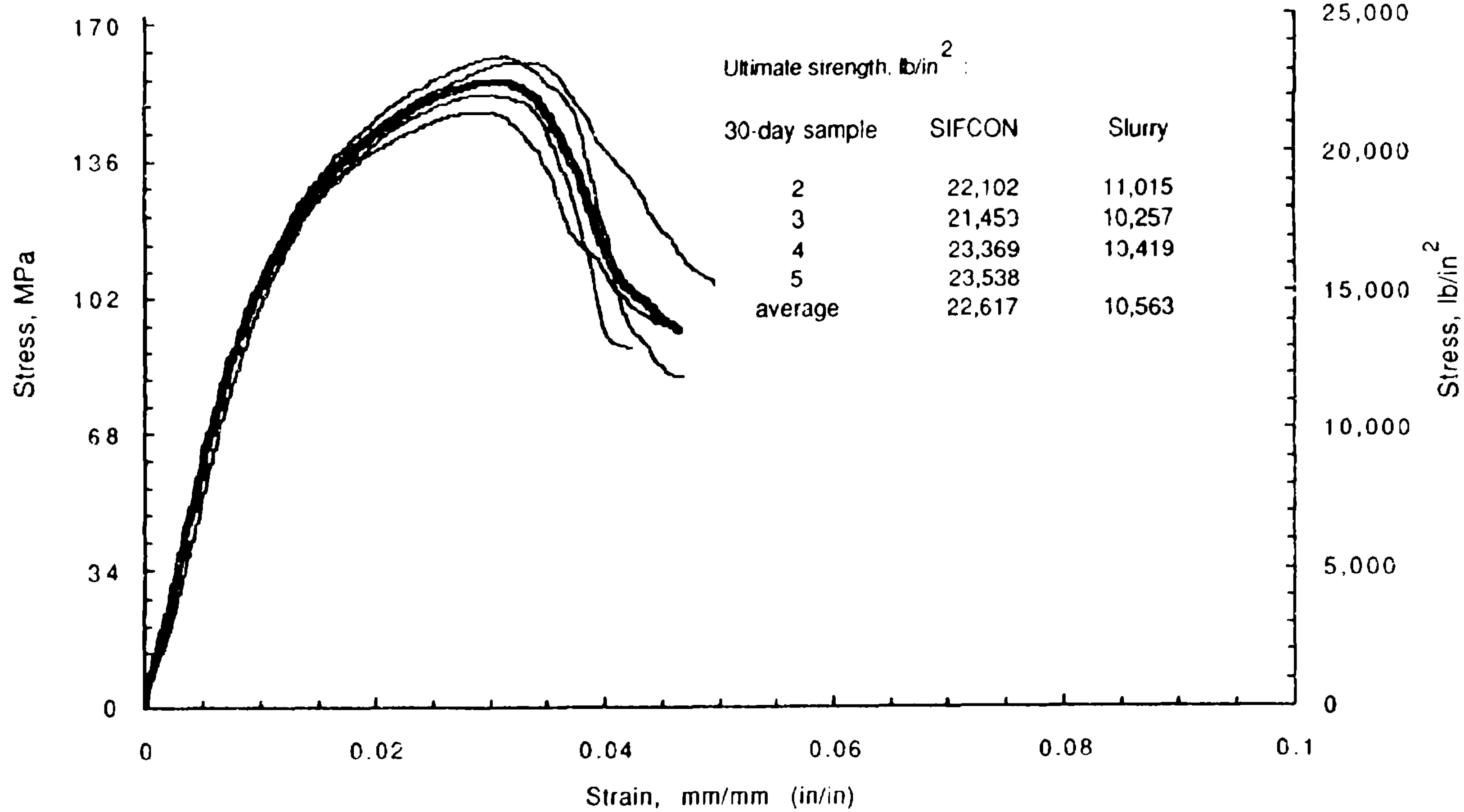


Figure B5. S-5M100-10-37-0 (ZL 30/50) -- compression.

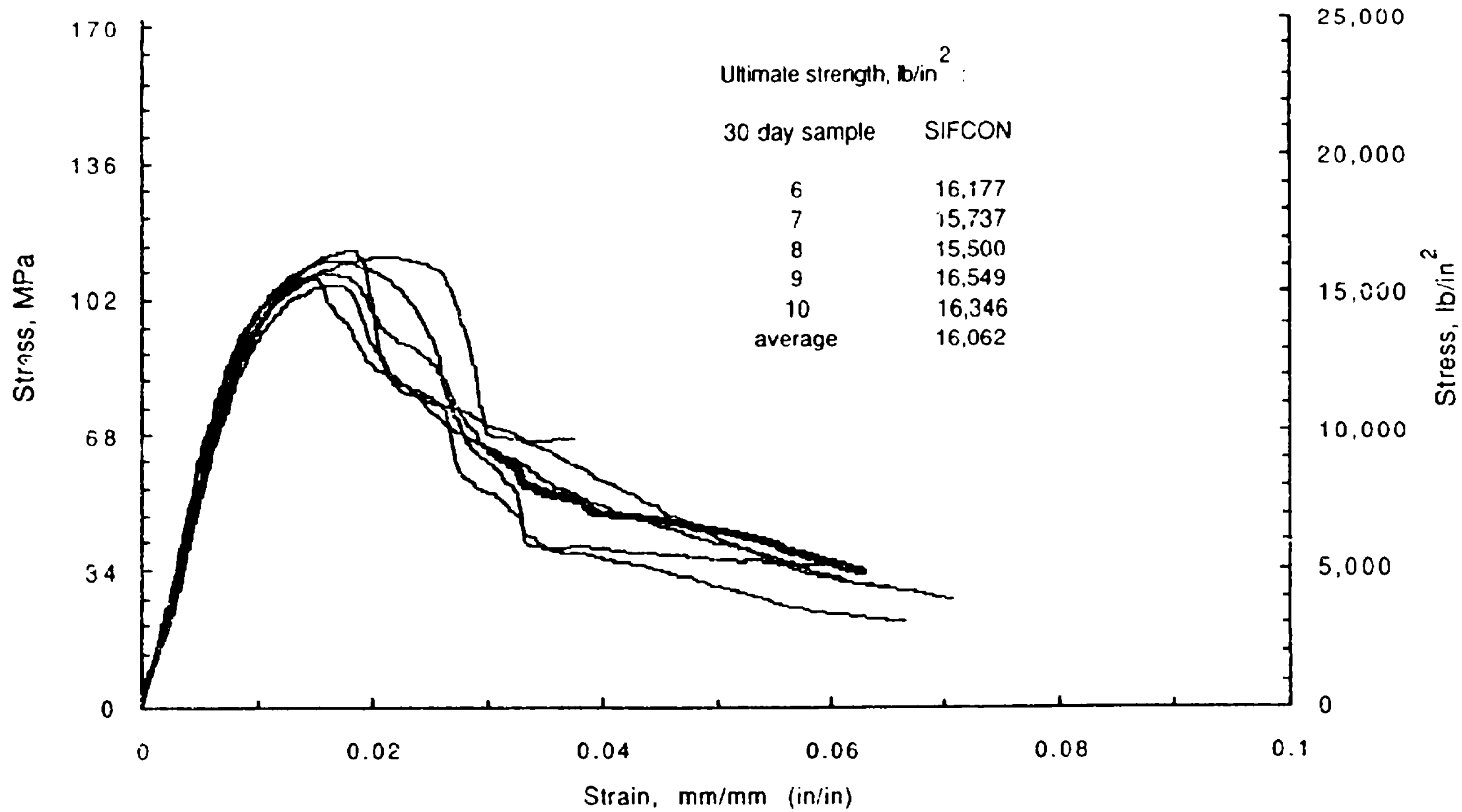


Figure B6. S-5M100-10-37-0 (ZL 50/50) -- compression.

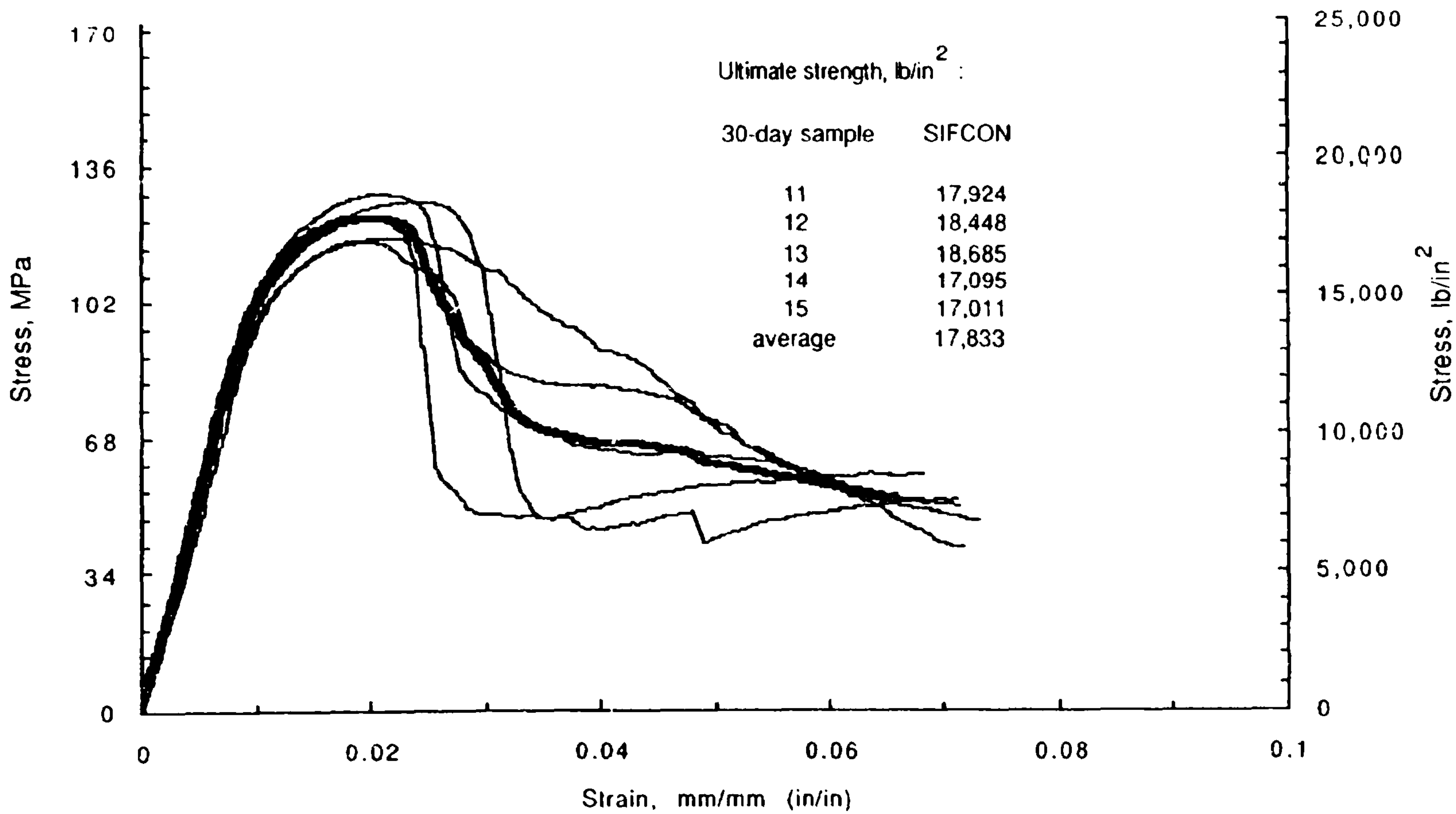


Figure B7. S-5M100-10-37-0 (ZL 60/80) -- compression.

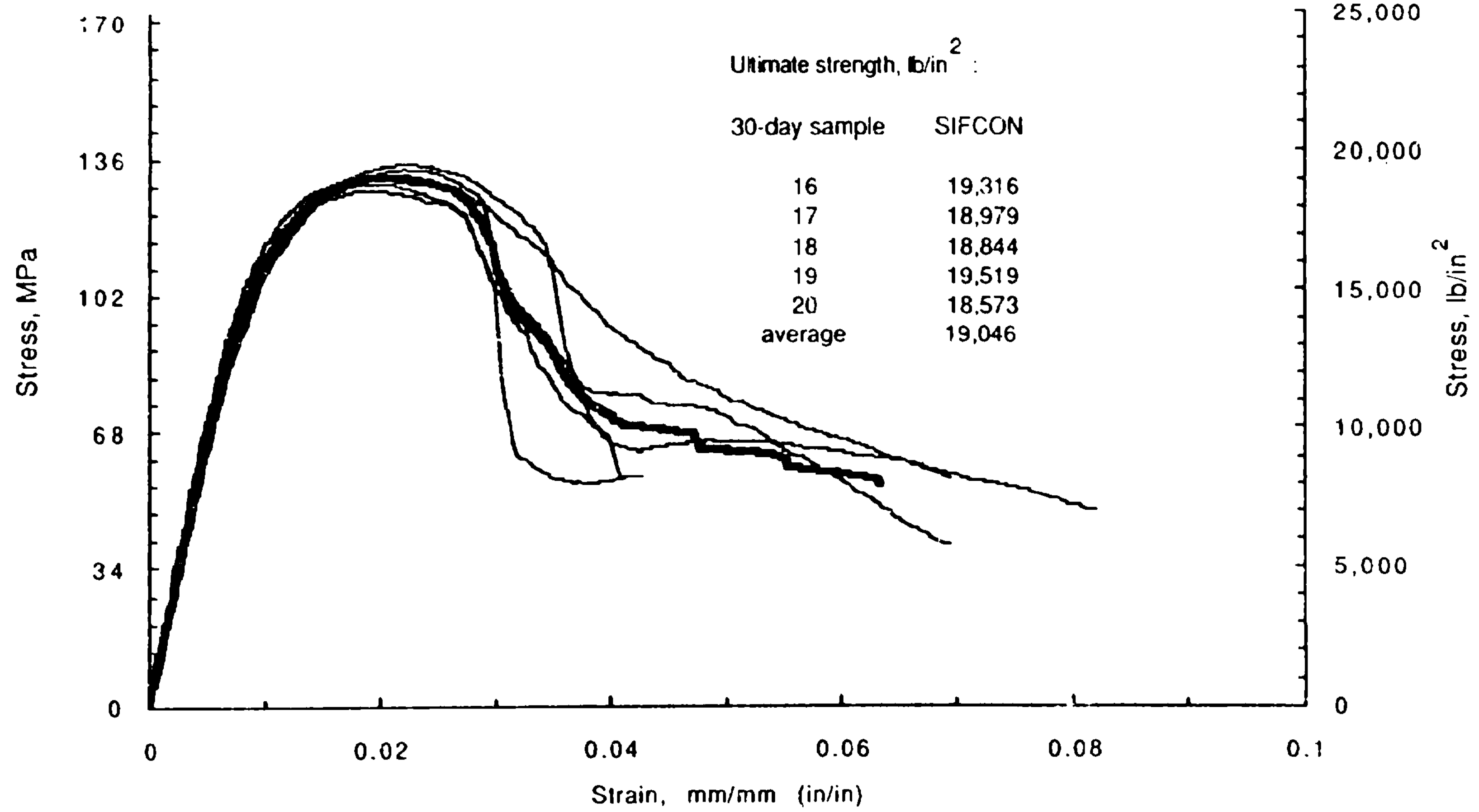


Figure B8. S-5M100-10-37-0 (aggregate and ZL 60/80) -- compression.

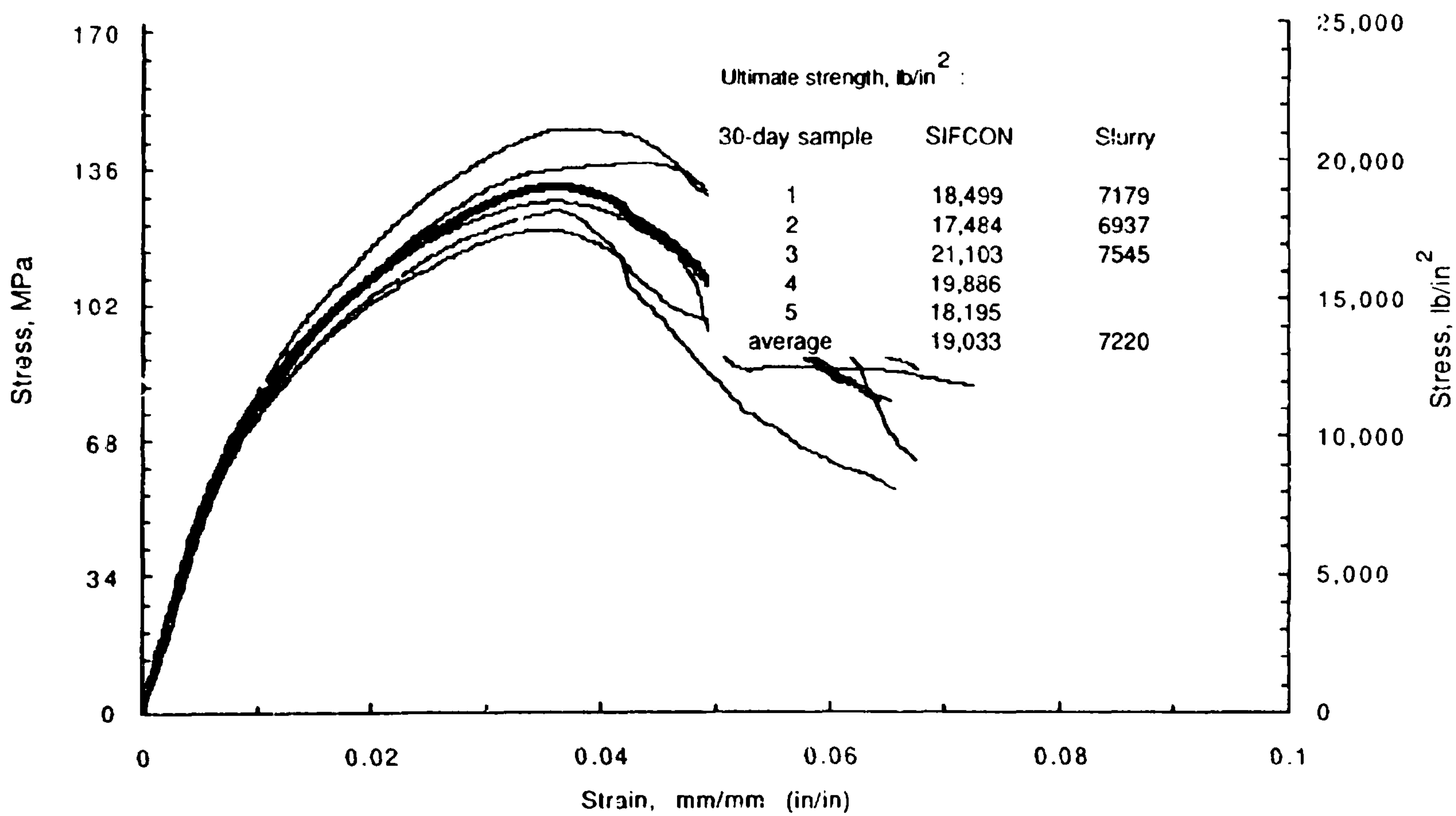


Figure B9. S-5M150-37-10 (ZL 30/50) -- compression.

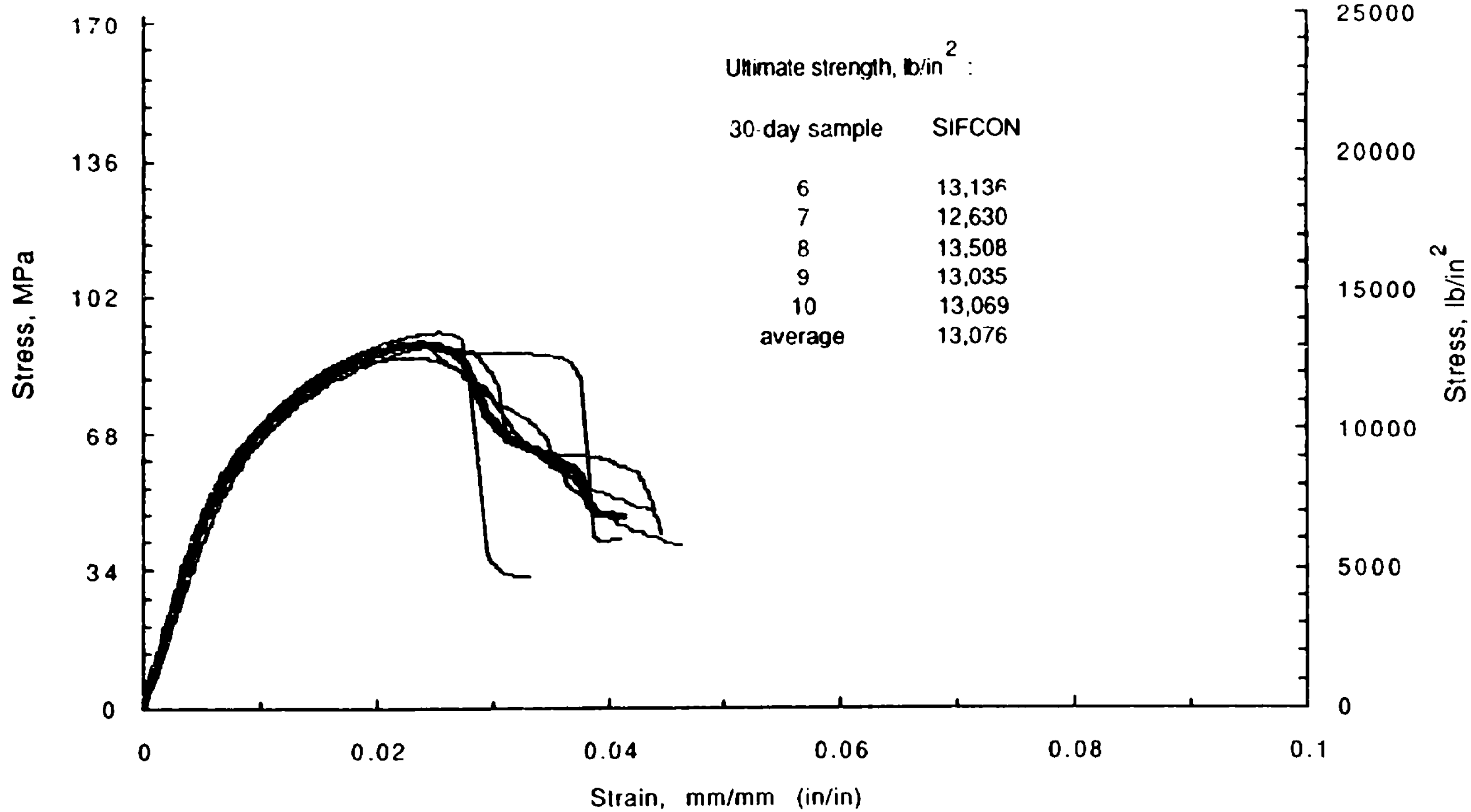


Figure B10. S-5M150-37-10 (ZL 50/50) -- compression.

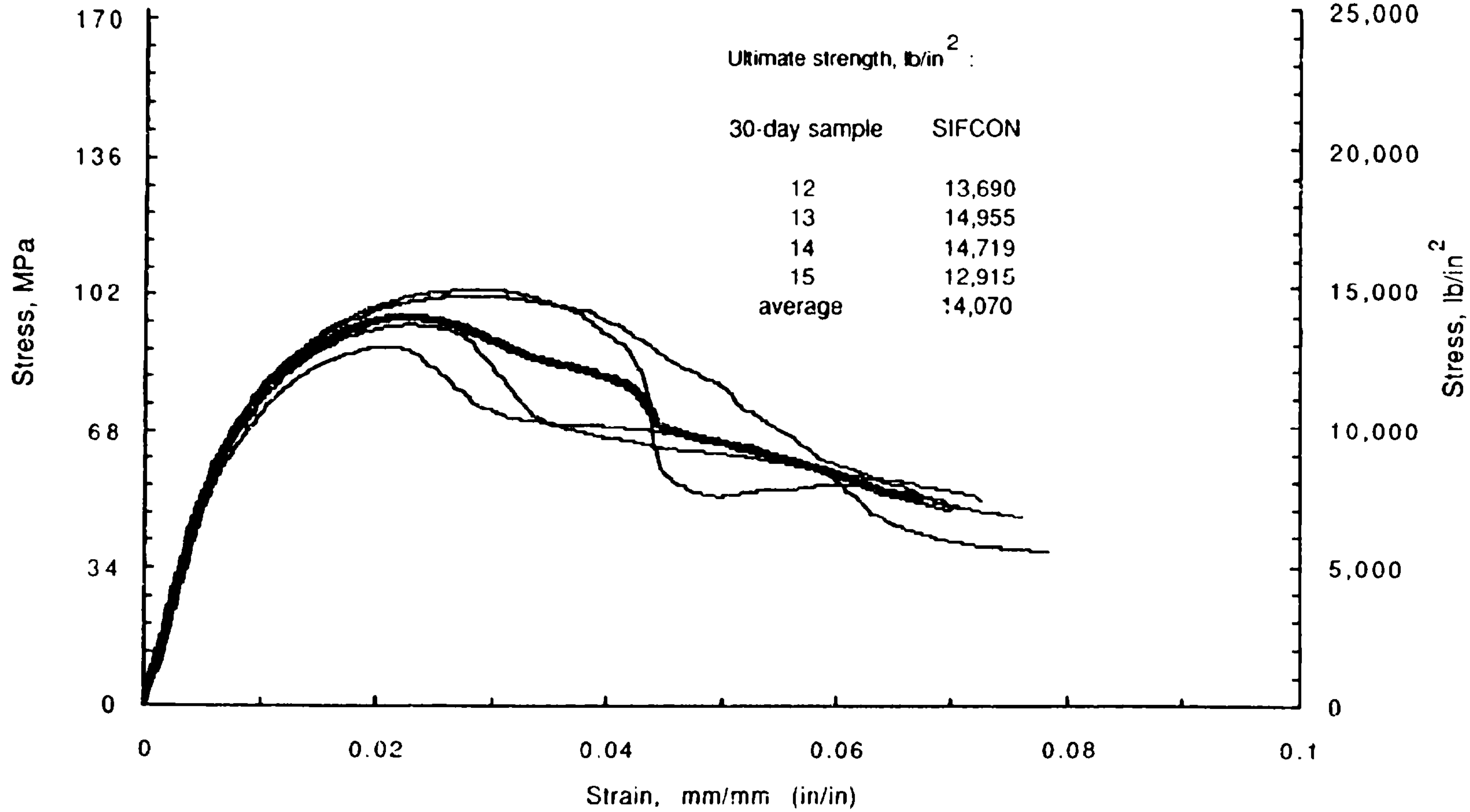


Figure B11. S-5M150-37-10 (ZL 60/80) -- compression.

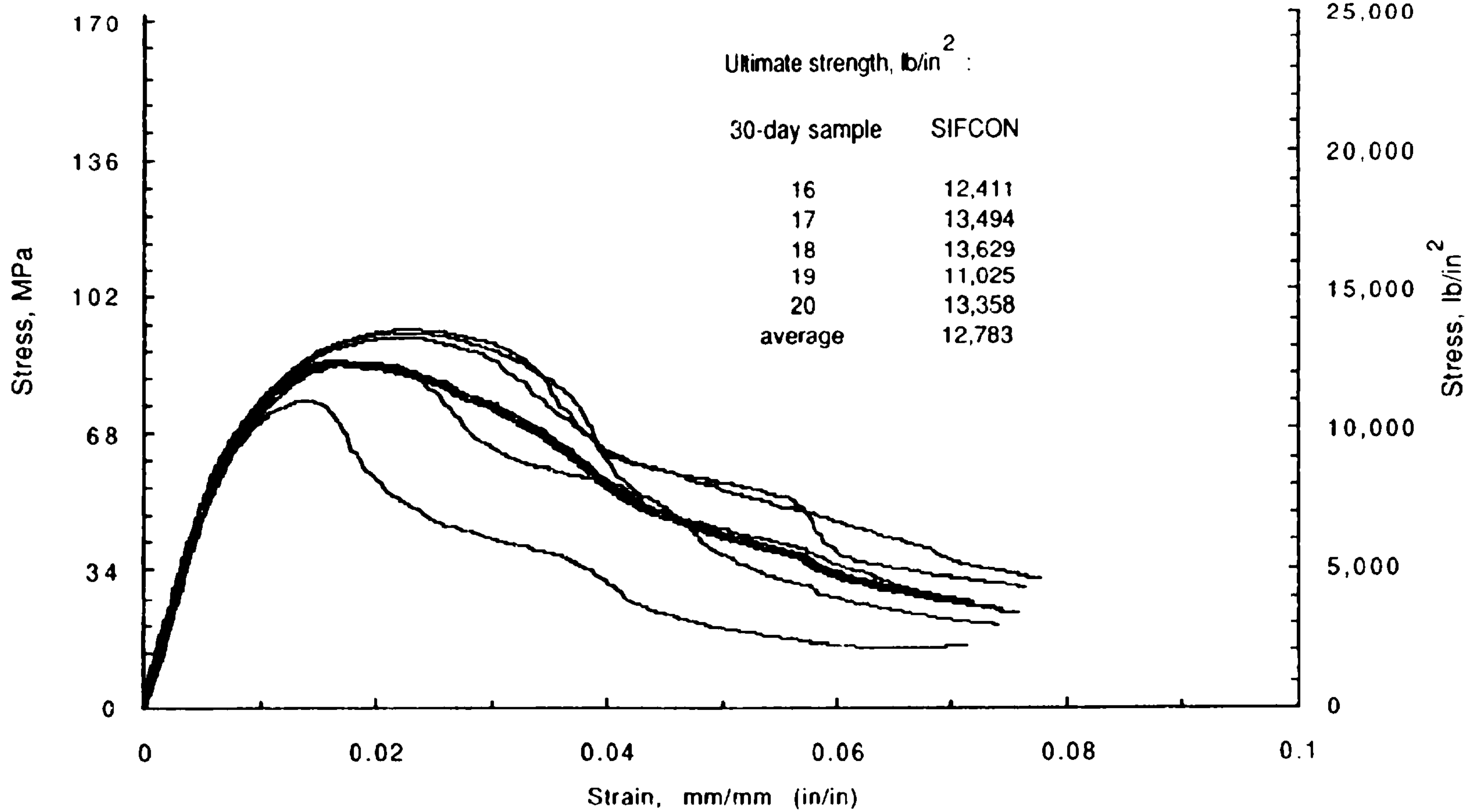


Figure B12. S-5M150-37-10 (aggregate and ZL 60/80) -- compression.

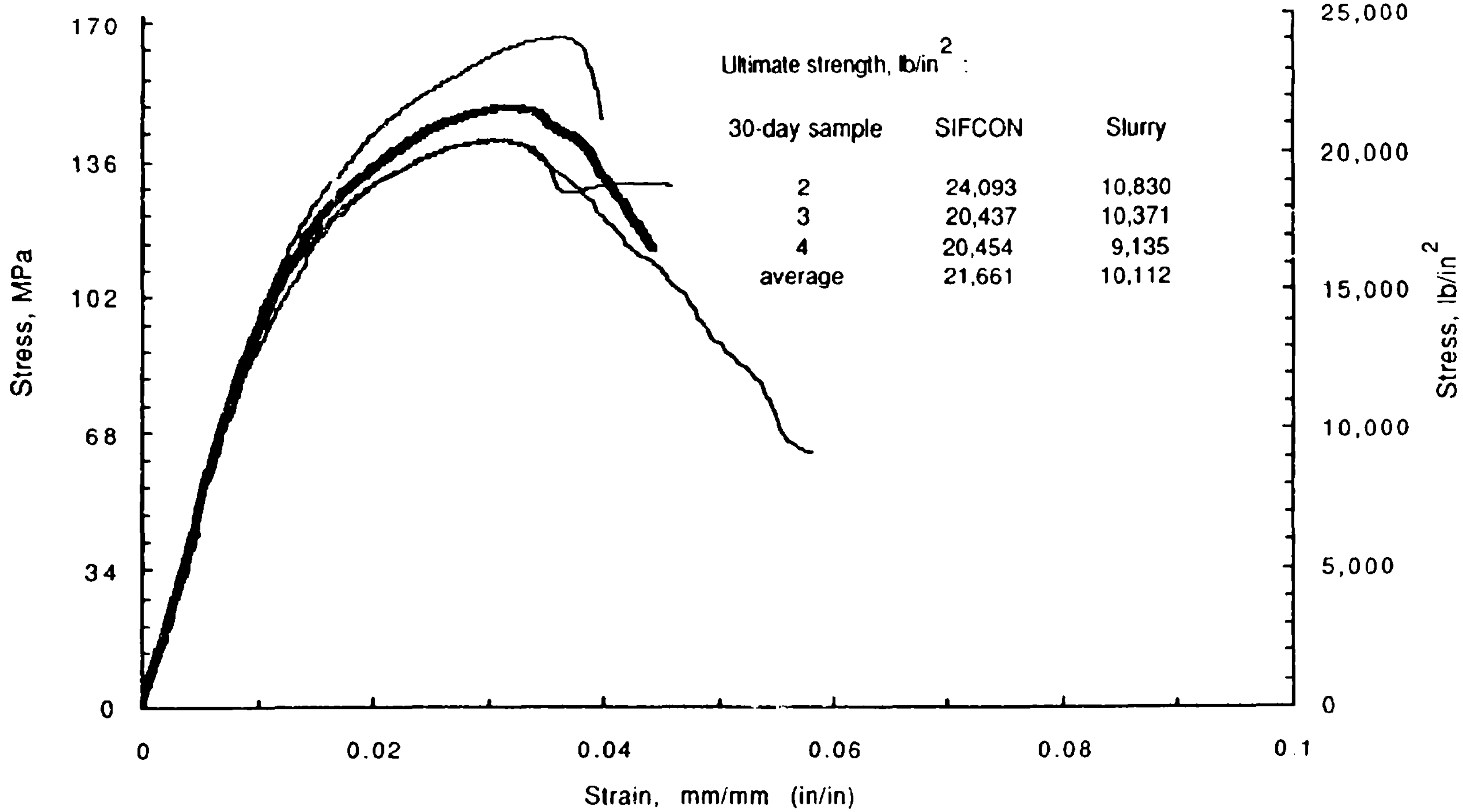


Figure B13. S-3M100-10-38-0 (ZL 30/50) -- compression.

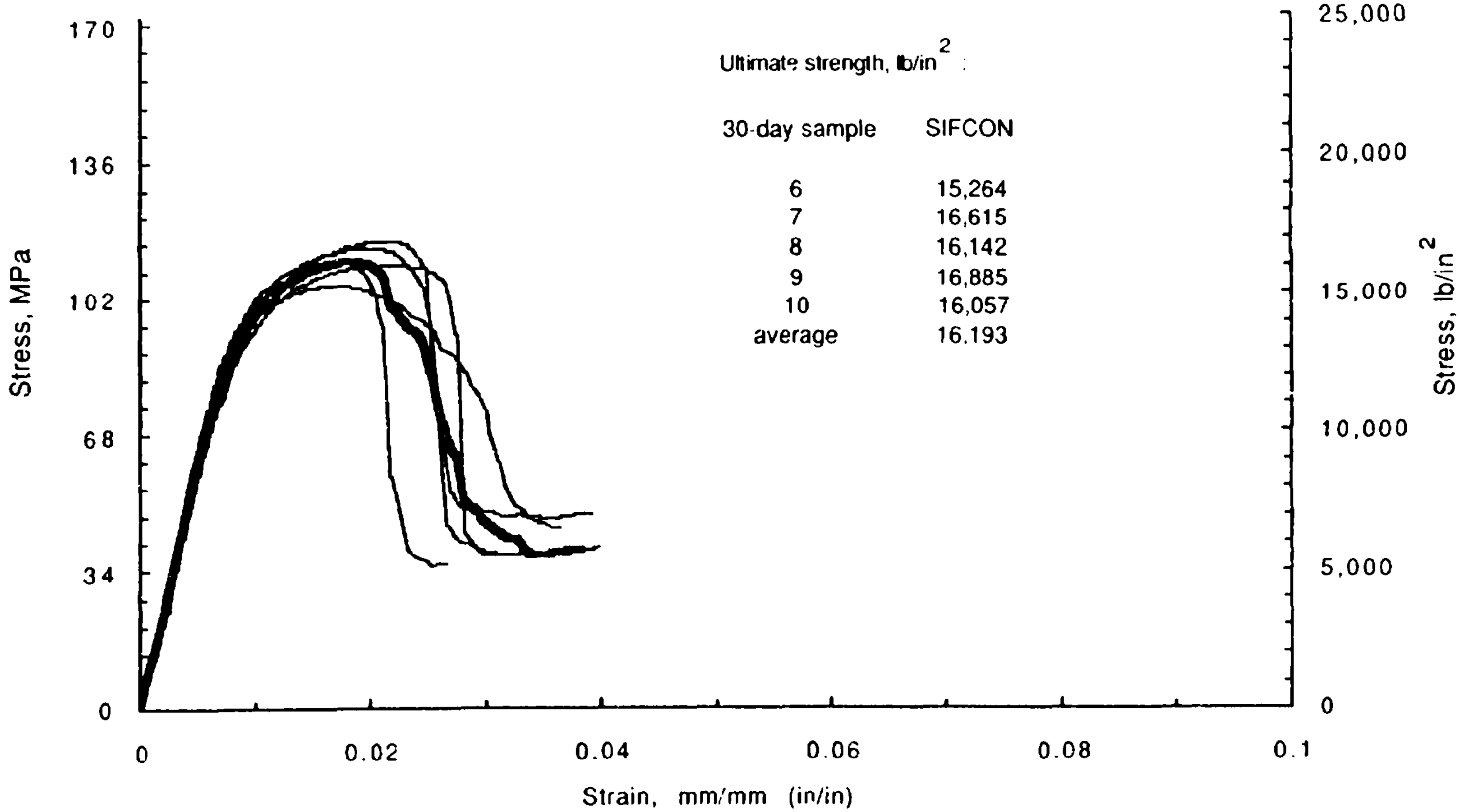


Figure B14. S-3M100-10-38-0 (ZL 50/50) -- compression.

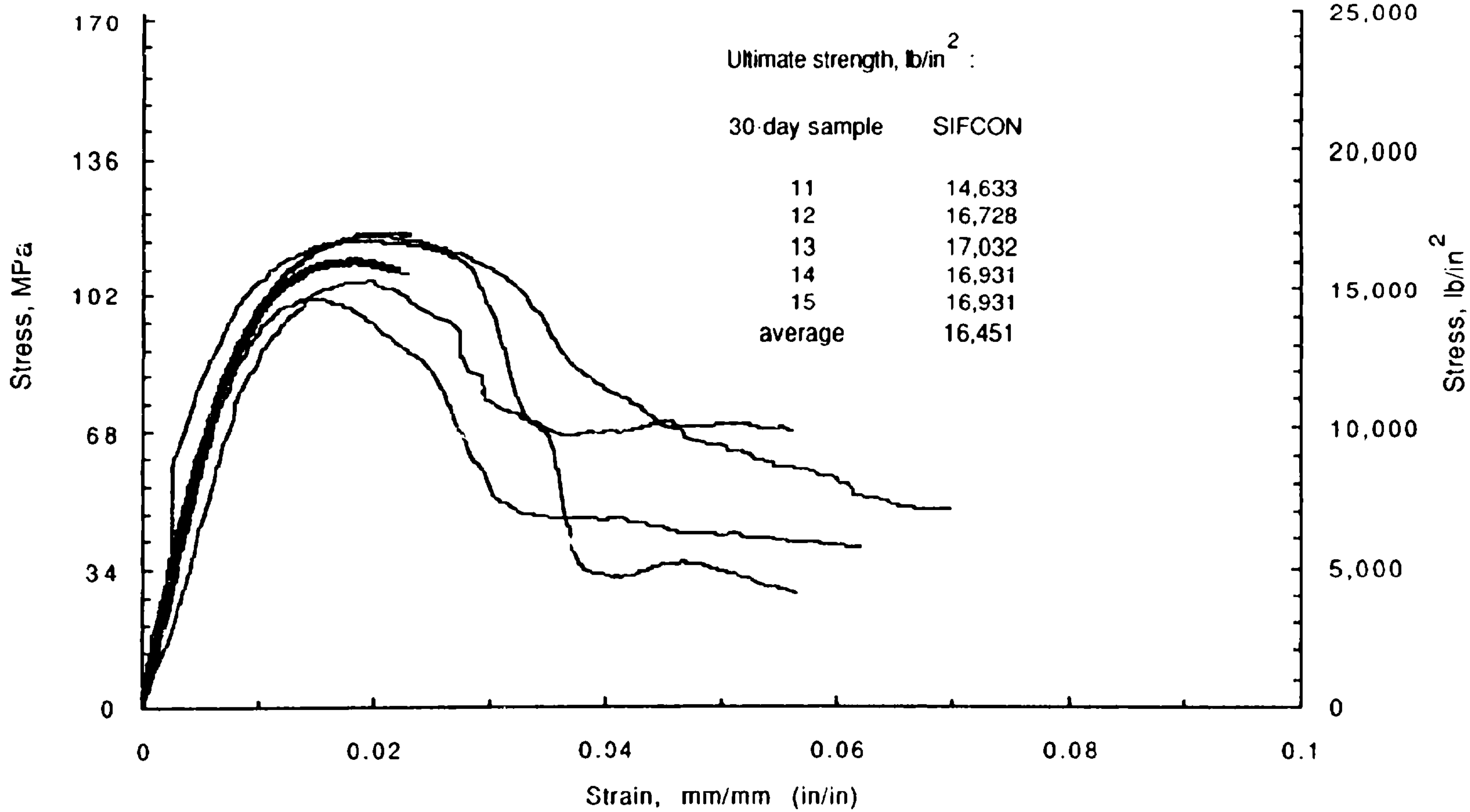


Figure B15. S-3M100-10-38-0 (ZL 60/80) -- compression.

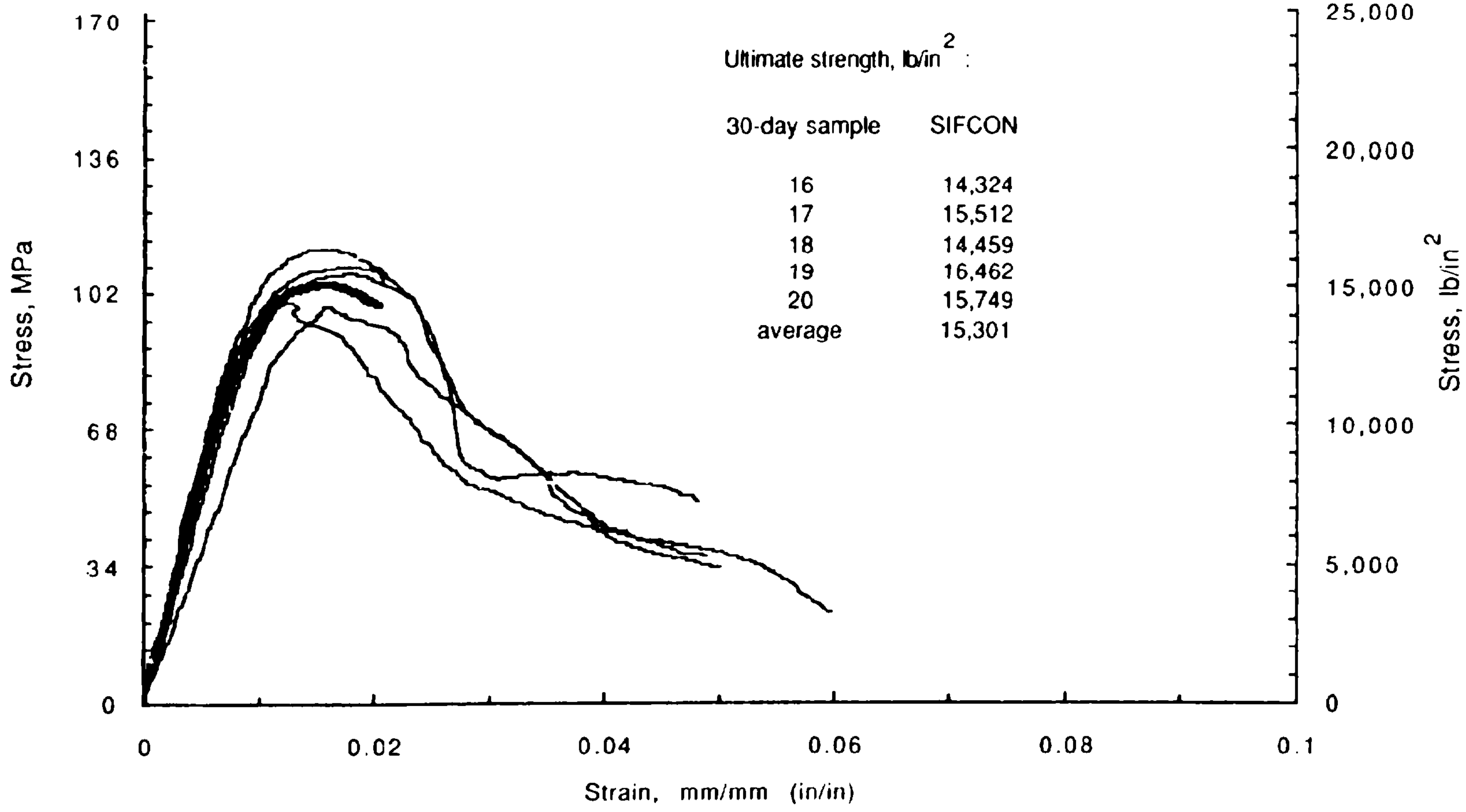


Figure B16. S-3M100-10-38-0 (aggregate and ZL 60/80) -- compression.

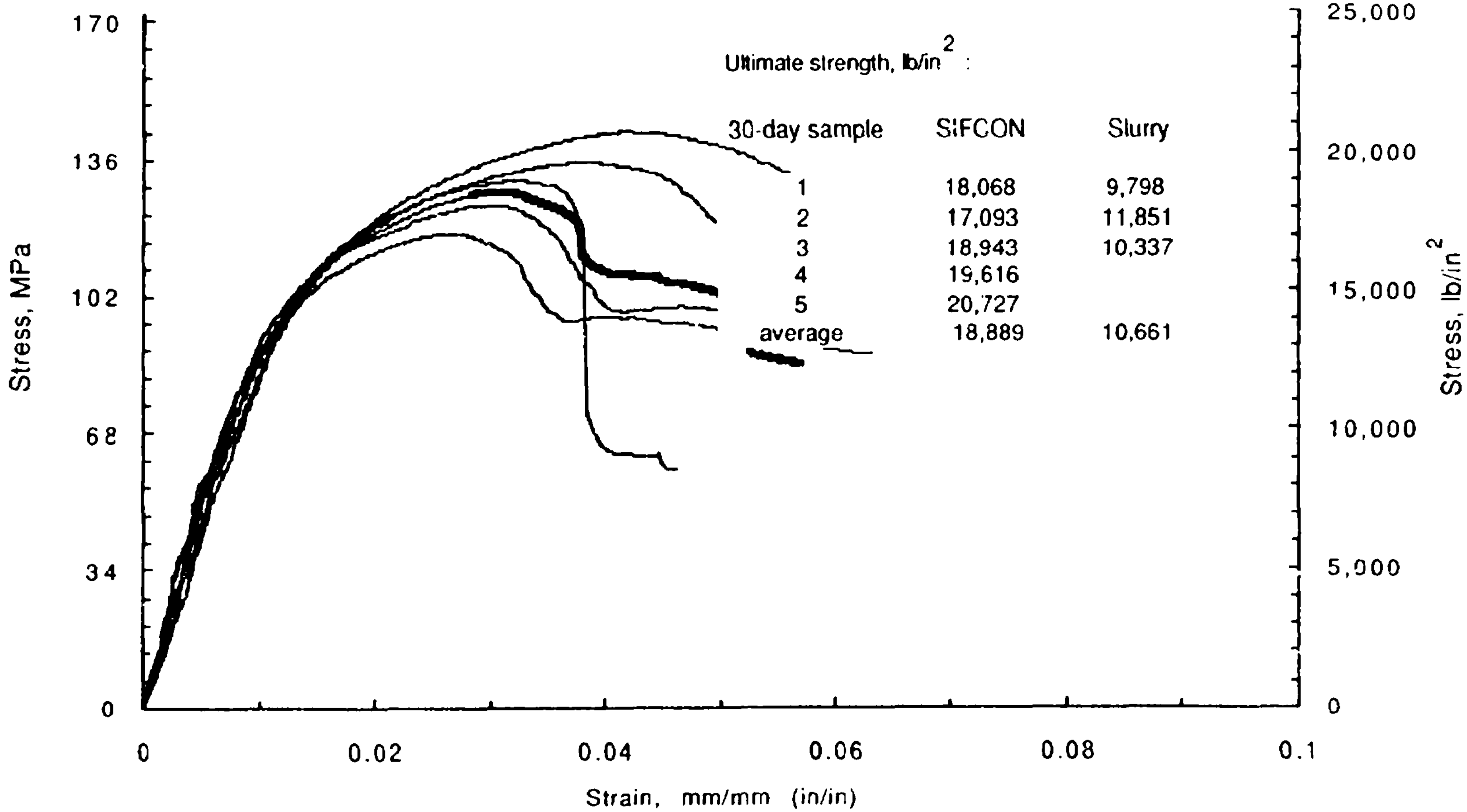


Figure B17. S-5M50-15-35-10 (ZL 30/50) -- compression.

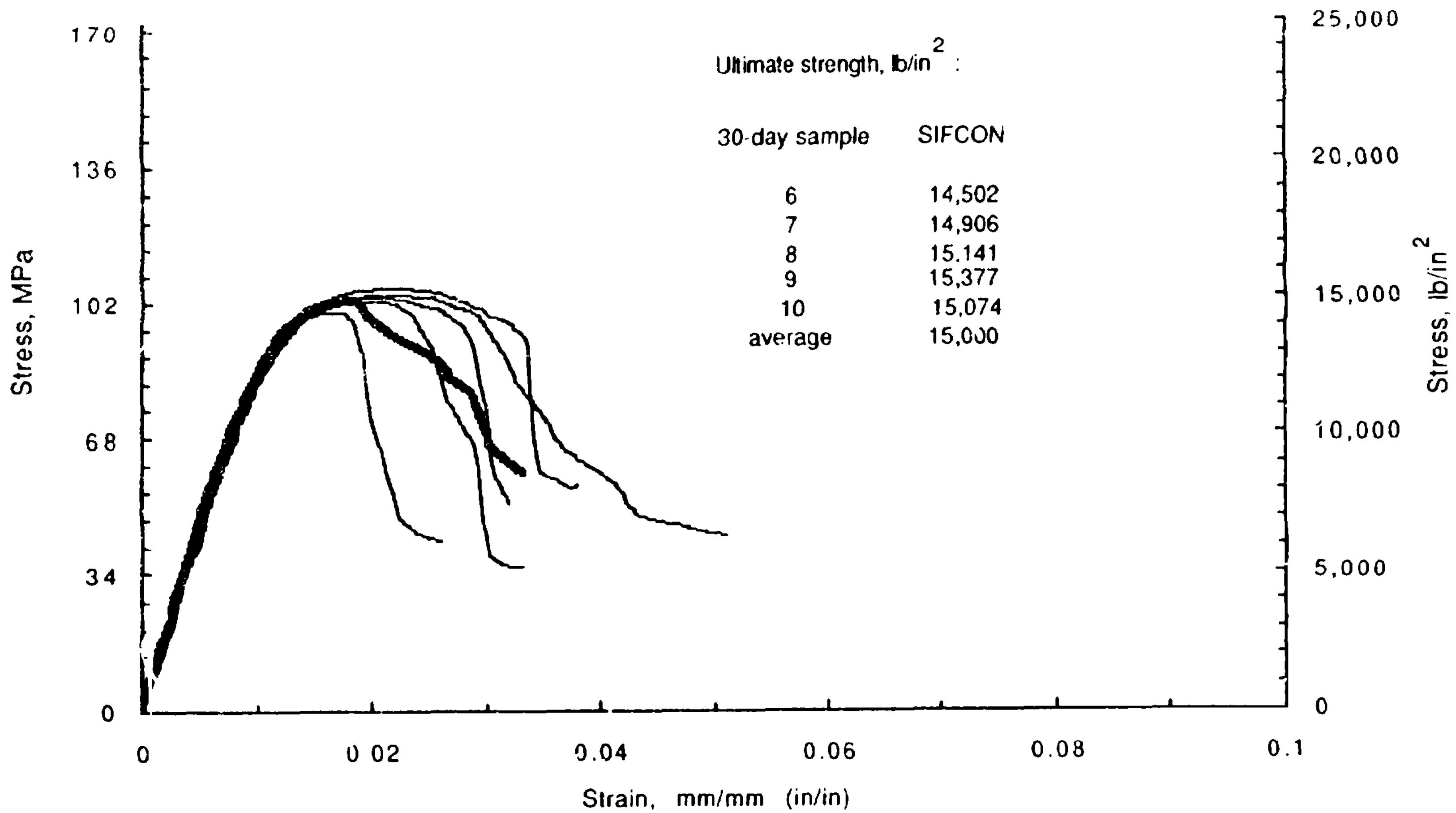


Figure B18. S-5M50-15-35-10 (ZL 50/50) -- compression.

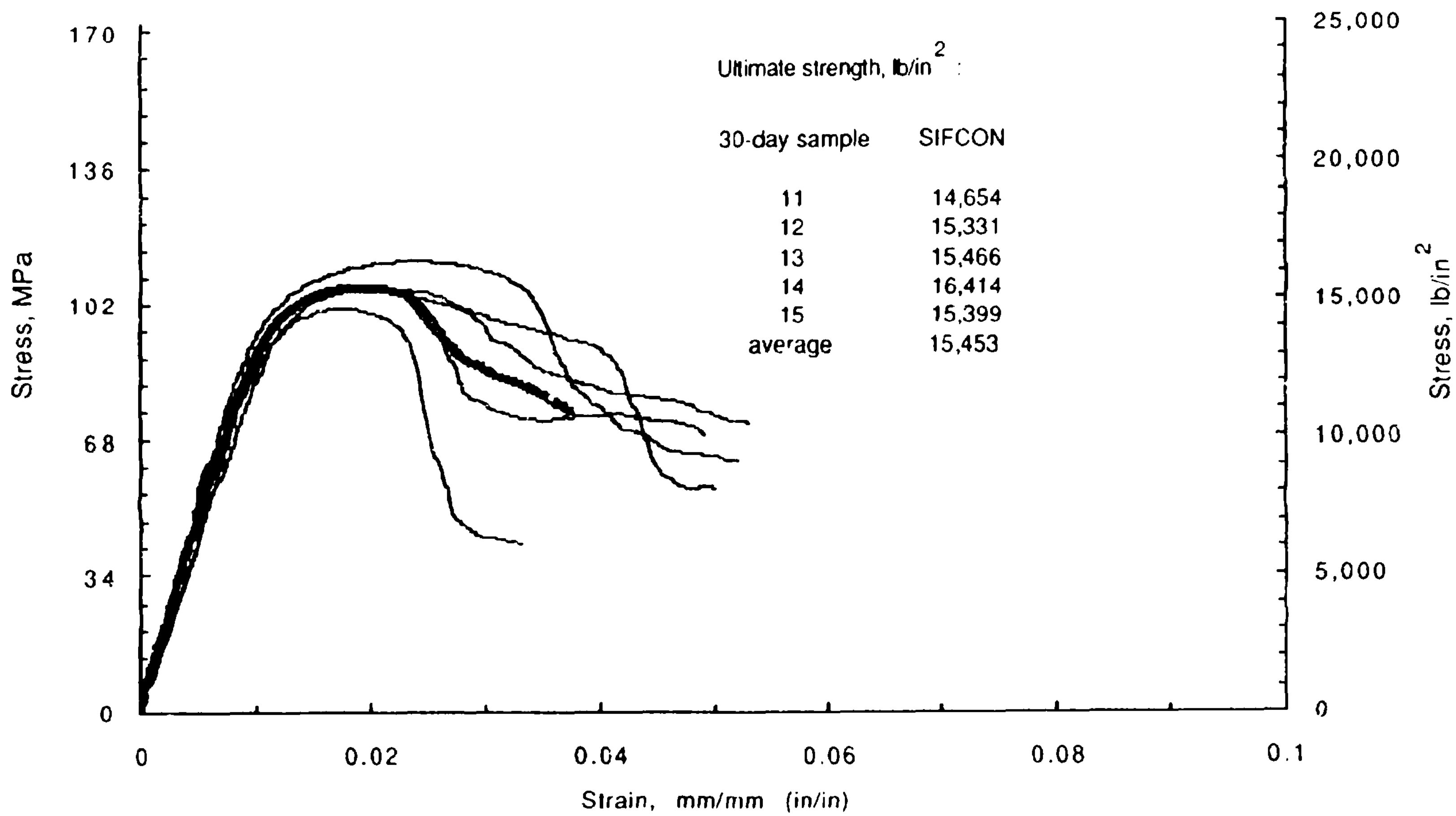


Figure B19. S-5M50-15-35-10 (ZL 60/80) -- compression.

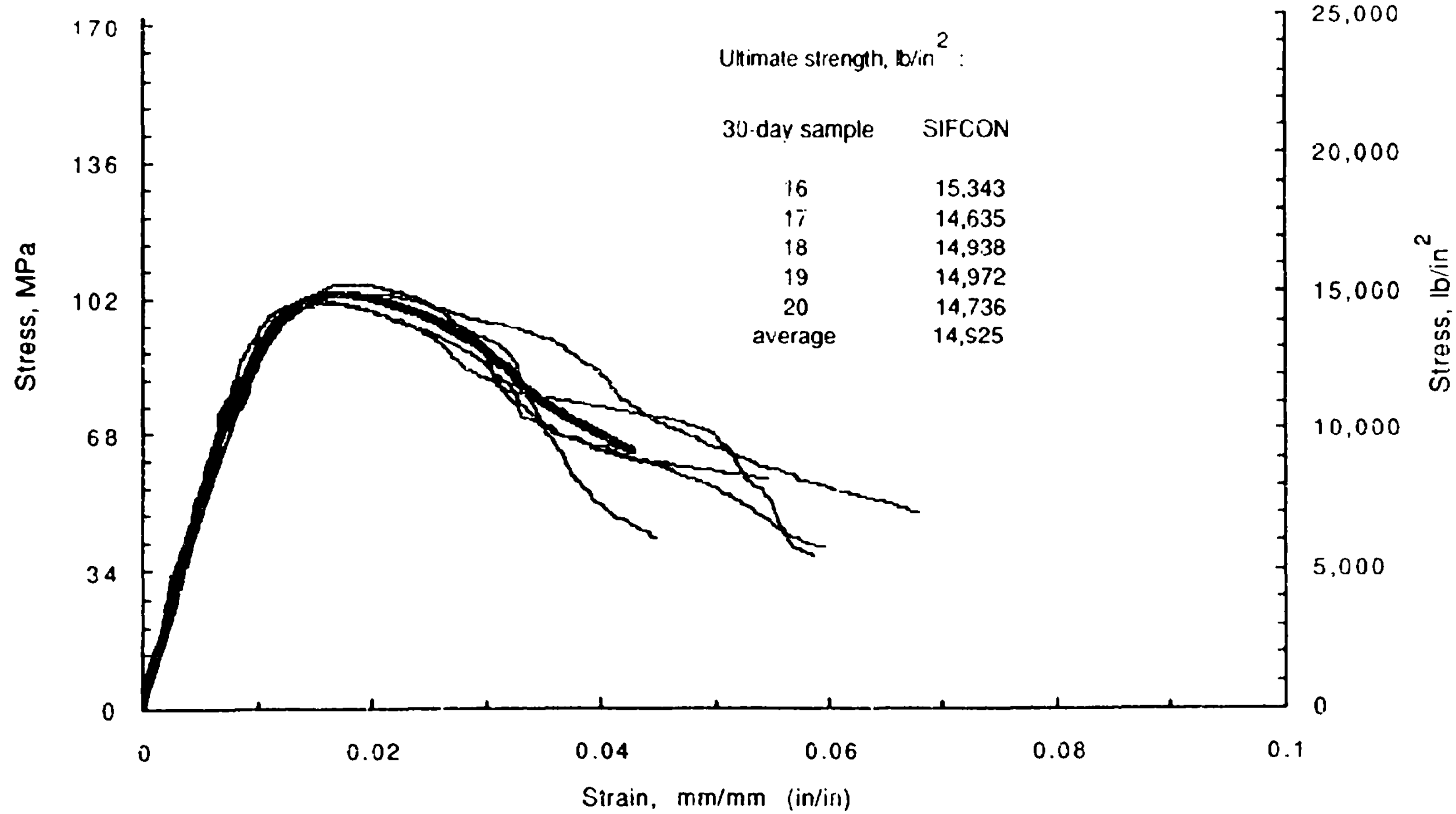


Figure B20. S-5M50-15-35-10 (aggregate and ZL 60/80) -- compression.

APPENDIX C
PROCEDURES CHECKLIST

This appendix contains a copy of the two-sided procedures checklist used by the laboratory technicians in preparing the major slurry mixes in the slurry infiltration phase of this program.

SIFCON SAND MIXES

Identification ____________________
Sand type ____________________
Mix date ____________________

I. Preparation

1. Dry out 200 lbs. of sand.
2. Weigh out the sand and absorption water noted in the "sand" boxes (over).

   Notes: a. Sand must be bone dry at weighing.
   b. Absorption water can be added to sand only if buckets are sealed.

3. Weigh the ingredients noted in the "slurry batch" box (over).
4. Fill large cylinder molds with the fiber noted in the "cyl." boxes (over).
5. Mark cube molds 1 thru 5 (3 cubes each).
6. Store all ingredients, molds, etc. in wet room (70 deg).
7. Be ready to make a batch of slurry using the program procedures.

II. Mix Day

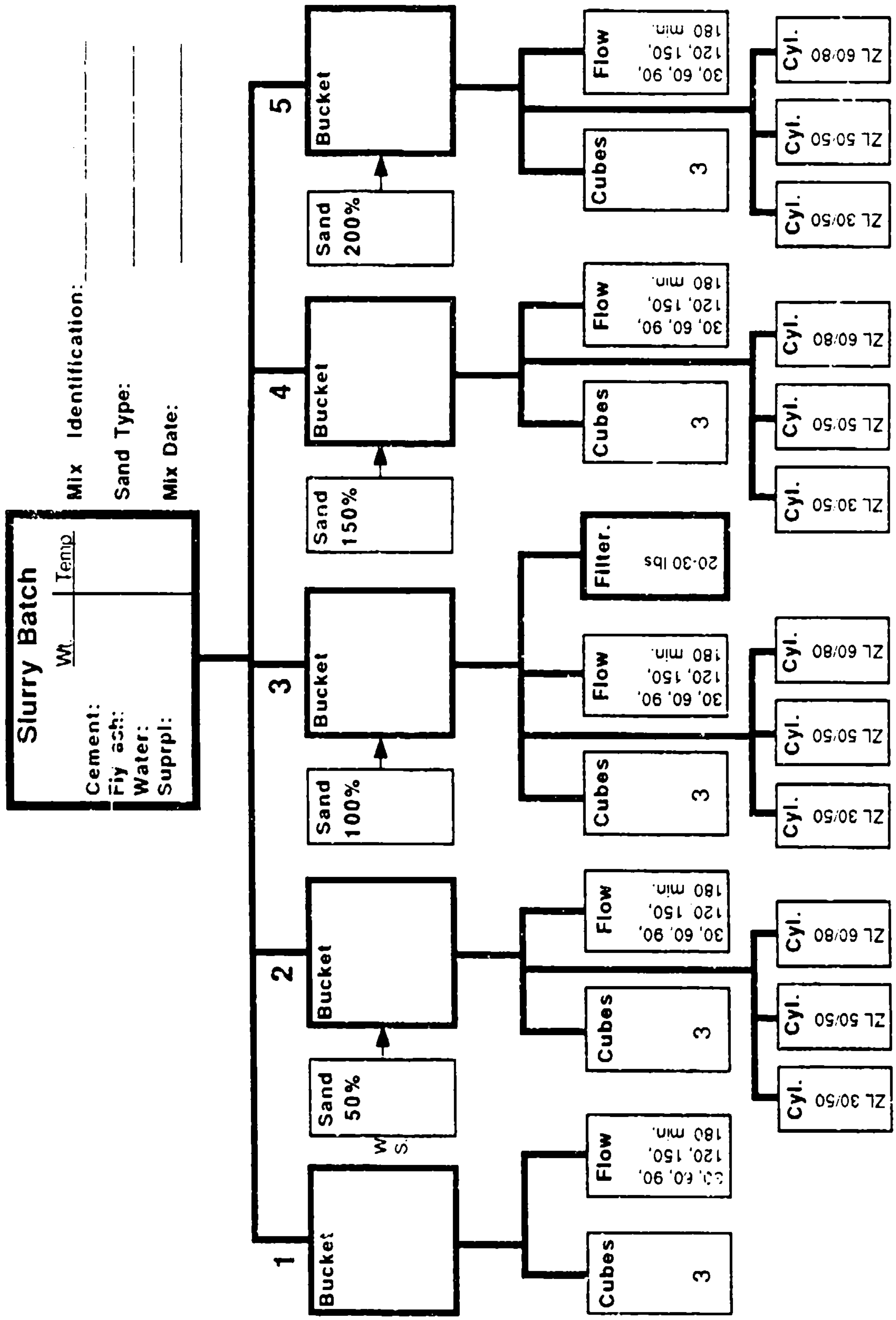
A. Run slurry mix using program procedures.

B. Bucket mixes
1. Weigh out the amounts noted in the "bucket" boxes (over).
2. Mix the sand and absorption water with the appropriate slurry.
   (Make sure each sand/slurry mix remains identified.)

C. Samples and Tests
1. Mold 3 cubes for each of the 5 mixes.
2. Mold the 3 SIFCON cylinders for each of the 4 sand mixes.
3. Place all samples in the wet room.
4. At T = 30 minutes begin taking flow/temperature measurements for each of the 5 mixes beginning with buckets #5 thru #1.
5. At the following times take flow/temperature measurements for each mix in the same sequence: T = 60, 90, 120, 150, 180 min.

D. Filtering Tests
1. Weigh out between 20-30 lbs of slurry from mix #3
2. Turn over slurry to EMCS

III. Testing
1. Strip molds the day after mix day.
2. Cut the SIFCON cylinders in half length wise.
3. Test the cubes for compressive strength at 30 days.


Slurry Batch
Wt.
Temp
Cement:
Fly ash:
Water:
Suprpl:
Mix Identification:
Sand Type:
Mix Date:
1
Bucket
Flow
30, 60, 90, 120, 150, 180 min.
Cubes
3
2
Bucket
Sand
50%
Flow
30, 60, 90, 120, 150, 180 min.
Cubes
3
Cyl.
ZL 30/50
Cyl.
ZL 50/50
Cyl.
ZL 60/80
3
Bucket
Sand
100%
Flow
30, 60, 90, 120, 150, 180 min.
Cubes
3
Filter.
20-30 lbs
Cyl.
ZL 30/50
Cyl.
ZL 50/50
Cyl.
ZL 60/80
4
Bucket
Sand
150%
Flow
30, 60, 90, 120, 150, 180 min.
Cubes
3
Cyl.
ZL 30/50
Cyl.
ZL 50/50
Cyl.
ZL 60/80
5
Bucket
Sand
200%
Flow
30, 60, 90, 120, 150, 180 min.
Cubes
3
Cyl.
ZL 30/50
Cyl.
ZL 50/50
Cyl.
ZL 60/80